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Essays on Economics of Education

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Abstract

Essays on Economics of Education

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This dissertation studies the role of the peer gender composition and the teacher gender in the education production function. Specifically, I examine the role of gender on human capital accumulation through two key research questions. One, does the peer gender composition matter for students' educational outcomes? Two, what is the impact of teacher gender on the students' education choices? The first two chapters investigate the former using education policies in Korea, and Chapter 3 addresses the answers to the latter question using the classroom assignment structure.

The first chapter examines the extent to which the gender peer composition of schools matters in explaining the college enrollment and STEM gender gap. I take advantage of the high school assignment policy adopted in Seoul, Korea. I find that students benefit from attending single-sex school regarding college enrollment, especially 4-year university enrollment. Results also show that male students attending all-boys schools are 8 percent more likely to choose a STEM major in a college. I find little evidence that school gender composition affects the STEM outcomes of female students. The second chapter studies the effect of single-sex school on students' academic achievement and their track choice in high schools. Using a longitudinal data set of

students who entered high schools in 2010, I find that single-sex schools are causally linked with improved academic achievement for both boys and girls. Despite the positive associations of all-girls schools with education outcome related to math test scores, I cannot find any significant effects of all-girls schools on the choice of majors and advanced course-taking behaviors. In the third chapter, I explore the role of same-gender teachers on students' academic achievement, college enrollment and the choice of major exploiting plausibly exogenous variation in students' and teachers' assignment to the classrooms. While the test scores of female students are consistently improved when the female teacher teaches them at each grade, same-sex teacher effect does not emerge regarding the STEM-related outcomes.

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1. Introduction

Cultivating a Science, Technology, Engineering, and Math (STEM) workforce is a crucial component of a country's competitiveness, advancement of scientific innovation, and generation of economic growth. In recent decades, gender gaps in academic achievement favoring males have been substantially reduced (Grant and Behrman, 2010), and there were no gender differences in mean performance in math and science tests (Lindberg et al., 2010, Hyde and Mertz, 2009). Despite the significant improvements in the education and academic achievement of women, they are persistently underrepresented among STEM degree holders. Women hold as many undergraduate degrees as men, but they make up only 30 percent of all STEM degree holders (U.S. Department of Commerce). The lower likelihood of women choosing a STEM major in college correlates to the limited supply of female workers in STEM occupations. While women filled 47 percent of all U.S. jobs in 2015, they only held 24 percent of STEM jobs in the 2000s (Beede et al., 2017). This is a growing concern considering that the gender wage gap is relatively smaller in STEM jobs than in non-STEM jobs. Also, a significant part of the existing gender wage gap is explained by the differences in the choice of majors (Altonji et al., 2015).

This paper examines the effects of single-sex schooling on students' college enrollment and STEM major choice. I analyze the effects of single-sex schools on students' academic outcomes in the context of the Korean education system. Examining single-sex schools in Seoul is useful because of the potential in single-sex schools for addressing gender inequality in Korea. Gender inequality is pervasive and persistent in Korea, which ranked 118 out of 144 countries surveyed in terms of inequality (The World Economic Forum Gender Gap Report, 2017). Korea has the largest gender gap in earnings, which is 34.6 percent, among all OECD countries that provided data (OECD, 2017). Min (2017) estimates that 83.1 percent of college graduates in STEM majors are male compared to 16.9 percent of graduates who are females. On average, workers in STEM occupations earn 13 percent more monthly wages than workers in non-STEM jobs. In this sense, exploring the effect of single-sex schools on students' STEM outcomes provides insights to researchers and policymakers whether promoting the expansion of gender-segregated education can be beneficial for reducing the gender gap in STEM career choice and wage.

I avoid the problem of nonrandom selection of students into schools using a unique institutional feature in Korea: assignment of students into high schools by computerized lottery. The high school assignment of middle school graduates in Seoul, which I will discuss below in more detail, offers an opportunity to examine causal effect of single-sex schooling on college enrollment and students' STEM outcomes addressing concerns of endogenous sorting and differences in inputs that might be correlated with school type. Utilizing student-level administrative date from Seoul, Korea, I look at how gender peer composition affects students' post-secondary education outcomes including college enrollment and choice of STEM major.

I find that students benefit from attending single-sex school regarding college enrollment. Male students from single-sex schools are about 11 percent more likely to participate in a four-year university. Attending all-girls schools increase the likelihood of admission in a four-year university by 9 percent for female students compared to their counterparts in coed schools. Interestingly, I find differential effects of single-sex schools on students' STEM outcomes by gender. The results indicate that attending an all-boys schools increase the probability of choosing STEM major in college by 7 percent. In contrast, the findings of this paper demonstrate no significant effect of single-sex schools on female students' STEM outcomes.

This paper is closely related to an emerging body of literature that attempts to understand the persistence of the underrepresentation of women in STEM fields. Carrell, Page, and West (2010) found that female students' likelihood of taking future math and science courses and graduating with a STEM degree increases when they are assigned to a female professor. Bettinger and Long (2005) observed that female faculty members increase the probability of female students taking additional courses in math and geology. However, they identified the opposite effect for biology and physics courses. Griffith (2010) suggested that the types of postsecondary institutions that students attend and their educational experiences at those institutions have a great impact on students' STEM major persistence. Hill (2017) demonstrated that women exposed to a larger number of female college peers are more likely to choose female-dominated majors.

I also contribute to extensive studies attempting to understand the effect of gender peer composition and single-sex schooling on educational outcomes. An increase in the proportion of girls in a classroom has been proven to significantly affect educational outcomes for both boys and girls (Hoxby (2000), Lavy and Scholosser (2011)). Thompson's (2003) results indicated that women who attended all-girls high schools are more likely to major in sex-integrated fields over female-dominant fields compared to their counterparts in co-ed schools. Schneeweis and Zweimüller (2012) discovered that if girls were exposed to a larger number of girls in an earlier grade, they were more likely to choose a male-dominated school type. Anelli and Peri (2016) observed that male student exposed to over 80 percent of male peers are more likely to select a male-dominated college major in Italy. Hill (2017) demonstrated that an increase in the proportion of females in freshman cohort is associated with a rise in the graduation rate for male students. Similar to this paper's setting, Park et al. (2013) and Lee et al. (2014) estimated the causal effects of assignment to single-sex schools in Seoul on students' test scores and show the positive impact of the single-sex schools on boys' academic achievement.

This paper extends the analysis of the effect of single-sex education beyond academic achievement to examine other important decision such as college enrollment and STEM major choice under the upper-secondary educational setting. I add to the understanding of how peer gender composition affects education choice by showing that boys are benefited from single-sex schooling. This finding suggests that students' academic choices that are made in high school have a lifelong impact on students' major in college, careers, and wages. It is essential to understand the reasons for the underrepresentation of certain groups within the STEM field and, therefore, where the focus of educational and policy interventions should be placed to encourage STEM major participation.

The remainder of the paper is organized as follows. Section 2 presents information on the educational system and students' assignment policy adopted in Seoul, Korea. Section 3 describes the data and variables utilized in this paper, and Section 4 describes our empirical strategy. In Section 5, I present the results on the validity of the research design. I present estimates of single-sex schooling on college enrollment and STEM outcomes in Section 6. I differentiate single-sex school effects with other school quality measures in Section 7. Section 8 provides a conclusion of the study.

2. BACKGROUND

2.1 The Education System of Korea

In Korea, all students attend nine years of compulsory schooling: six years of primary education followed by three years of middle (lower-secondary) schooling. Graduates of middle schools or the equivalent can then pursue additional education at high schools. High schools are divided into general academic schools, vocational schools, and merit schools, which are foreign language high schools, science high schools, art high schools, and private autonomous high schools[1]. As of 2010, about 75 percent of Korean high school students attended general academic high schools (Statistical Yearbook of Education). General academic high schools provide advanced general education as well as elective courses, which students select based on their intended university admission.

Admission to general high schools differs across school systems. Students in major metro areas, designated "equalization areas," are placed in senior high schools based on a lottery system, while schools in other regions admit students based on the students' prior school records and school-administered entrance examination. Vocational and special-purpose high school applicants select their school of choice and are accepted based on that school's entrance exam and their middle school academic records.

One year after high school entry, students choose their academic track regardless of their school type. Most schools provide a math-science track and a liberal arts-social science track, except for art, foreign language, and science schools. Students focus on advanced courses within a given track; this choice is crucial in Korea. When students apply for college admission, those who choose a math-science track mostly apply to STEM-related majors, fields, or departments. Students in liberal arts tracks,

[1] Vocational high schools provide education for students who want to enter a specific profession. They offer general secondary education in the first year, with specialized courses in the fields of agriculture, industry, commerce, and so on in the final two years. Merit high schools are established to provide elite education for talented students in a variety of fields. Even though these schools are located within HSEP school district, they are not subjected to the HSEP and are operated independently regarding school budget, curriculum, and so on.

however, apply to liberal arts or social science major. The choice of academic track in high schools has a substantial long-term impact on a student's future career.

If a student chooses a math-science track, the College Scholastic Ability Test (CSAT) consists of Korean, English, type 2 mathematics, and science subjects including physics, chemistry, geology, and biology. Students in the liberal arts-social science track take a CSAT exam containing Korean, English, type 1 mathematics, and social science subjects including political science, economics, geography, philosophy, and more. Students are free to choose their academic track; past test scores and student characteristics are not considered by schools or teachers when students decide on a track choice. There are no minimum or maximum slots available for the students within each track. Changing the academic track is rare because students apply to a postsecondary institution in 12th grade, and it is difficult to catch up on the necessary coursework. Enrollment in STEM major (fields or departments) at postsecondary institutions requires advanced math and science courses.

High school seniors can apply for either two-year colleges or four-year colleges at the end of the high school years. For either type of college, the college admission is determined by two primary elements: the CSAT and the academic activity records from high school. In senior year of high school, students take the CSAT, which is administered by the Korea Institute for Curriculum and Evaluation. With a few exceptions, the CSAT counts for 70 percent of the overall selection for colleges and universities, with the student’s high school record contributing only 10 percent. Due to the importance of the CSAT score on college admission, high school curricula are heavily directed toward preparing students for the CSAT.

Most four-year universities are comprehensive, providing education in a broad range of sciences, social sciences, the humanities, engineering, and business. In general, a four-year university is considered to have a better curriculum, faculty and school facilities and higher tuition. The second dominant type of post-secondary institution is the two-year college, which focuses on vocational education related to the field of study, including a range of occupations in engineering, health, and business (OECD, Reviews of Tertiary Education-Korea). Colleges have a much lower status compared to universities. Anecdotal evidence suggests that some companies and government agencies do not hire college graduates. Students would typically not consider applying to colleges if they have a chance at attending a university. Four-year universities require higher CSAT scores and stronger academic activity records for admission than two-year colleges.

2.2 High School Assignments in Seoul

Before 1974, Korean high schools could choose their students based on the students' scores on the entrance examinations administered by individual high schools, resulting in clustering by family background and substantial differences between schools in students' academic performances (Park et al. 2013). The High School Equalization Policy (HSEP) was designed to alleviate inequality among high schools and prevent excessive competition for acceptance into the elite high schools, which caused overspending on private tutors and institutes[2]. The HSEP was first introduced in Seoul and Busan, the two largest metropolitan areas in Korea. The policy was then expanded to cover the three next largest metropolitan regions of Daegu, Inchon, and Kwangju in 1975. As of 2001, the HSEP covered all seven metropolitan areas and 11 provincial cities (Kim et al., 2008).

The HSEP created a natural experiment in which middle school students are randomly assigned to high schools within their school districts of residence by a computerized lottery system. Student mixing in the HSEP areas is quite thorough since the area of a typical enrollment zone is rather large. For example, Seoul, with its over 10 million habitants, is divided into 11 enrollment zones.

In 2010, the Office of Education at Seoul Metropolitan Area introduced the modified version of the equalization polity to respond to growing concerns for limited school choice, allowing students to list up to four schools that they prefer. There are three rounds of admissions to high schools in Seoul. In the first round, which occurs in the spring semester, the application is determined through an application process. Students can apply to one of merit high schools and vocational high schools. Schools select students based on their academic performance and recommendations from principals and teachers from middle schools. Once selected, students must attend the school that they are admitted. The second round consists of a lottery for general high schools and

2. Families spent $200 per month per student for private tutoring on average in 2008. This amount indicates a 0.2 percent point increase in private tutoring expenditure compared to the previous year.

autonomous public high schools. Students can list preferences up to four general high schools within their school districts. The lottery provides entry into the general high schools. Finally, if students fail to enter any of the schools they listed in the second round, students are randomly assigned to high schools with vacant seats in their school districts.

The assignment of students to general high schools is administered by the Office of Education in the Seoul metropolitan area. While the detailed algorithm of computerized lottery system is confidential, the Office of Education provides general procedure on student assignment. First, the Office of Education determines the number of total seats available in all high schools in their region. Second, middle school graduates send their high school application to the Regional Office of Education. Third, the computer program allocates high school applicants to the set of relevant high schools. Up to this stage, student's academic records at the middle school are not used in the actual assignment process.

Once qualified, only the individual’s residential address as of the last academic year in middle school is utilized for the lottery[3]. Therefore, if the student wants to take part in a high school lottery in a different school district, his/her family has to move to the new district before the last year of middle school starts. The high school assignment is

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[3] An academic year runs from March to February of the following year. The high school assignment is based on the applicant's address as of August in the last academic year during middle school. Not only the academic records but the location of middle school that high school applicant attended is not considered for the lottery system.

applied regardless of whether schools are coeducational or single-sex, as well as public or private.

One can think that students might move their residence to a new school district for any reason, including their dissatisfaction with the original school assignment. This seems unlikely because students are subject to another random assignment in the new school district. In other words, there is no guarantee that students can choose either single-sex school or coeducational school with certainty even if they have a specific preference about it. Discussing possibility of non-compliance, Park et al. (2013) and Sohn (2016) showed that the actual percentage of households moving into a different school district during the periods of high school application is very small and concluded that non-compliance is not likely to cause severe distortions in the estimates of the causal effect of single-sex schools in Seoul. Also, there have been continuous regulation changes that restrict students' school transferring within/between school districts to avoid Tiebout sorting [4].

Private schools in Seoul are also subject to the high school assignment process. Students attending private and public schools do not differ significantly in terms of socioeconomic background (Park et al., 2013). Both public schools and private schools in Korea have been made homogeneous by uniform and centralized set of education policies

[4] School transferring is available if 1) a student moves from another metropolitan area/province, 2) a student is a victim of school violence, or if 3) a student has trouble commuting due to a severe illness. If a student falls in one of these three situations, they are randomly assigned to schools with a vacancy within the school district.

regulating the curriculum and teacher's qualification under HSEP. The Ministry of Education provides a standardized national curriculum, based on either designated or certified textbooks. The central and local government fully funds teacher salaries and operating expenditure for public schools and private schools as well as single-sex schools and coed schools. All the general high schools in Korea impose the same amount of tuition for students.

Private schools are founded and owned by a private entity and have rights to select teachers. Central and local governments govern teacher selection and appointment into public schools. Public school teachers need to meet a qualification test to become a teacher and are all public employees of the government (Sohn, 2016). On the other hands, each private school is in charge of the selection and appointment of teachers once they meet the qualification required by the government (Kim et al., 2008).

3. DATA

Our primary data set is the Seoul Education Longitudinal Study of 2010 (SELS 2010), which surveyed 10th-grade students, parents, school, and teacher in 2010. Data are available through 12th grade, with a follow-up survey after high school graduation on postsecondary outcomes.

There are 235 academic high schools in Seoul, excluding one high school that is operated by the central government and five art and athletic high schools. Students in the 10th-grade panel were sampled by stratified two-stage cluster sample design. First, 60 general high schools were randomly chosen from the population of 198 general high schools, 13 autonomous high schools were randomly selected from the entire 21 autonomous high schools, and all 10 special purpose high schools are surveyed. Second, two classrooms were then drawn randomly within the sample school. The base line sample consists of 5,240 of the 6,456 targeted students in 2010. In 2013, two months after high school graduation, students were surveyed about their postsecondary outcomes at that point; 83 % of high school graduates from the original survey respondents, are interviewed. 70% of the respondents are attended in university, 12.8% are preparing for college entrance, 11.5% are employed, and 4.3 % are unemployed and looking for a job.

In the 2010 baseline survey, SELS collected a variety of information on students' academic achievements, track choice, attitude towards study, interest in specific subjects, students' demographic characteristics, family backgrounds characteristics, teacher characteristics, and school characteristics. SELS re-interviewed respondents in the original sample to obtain information on students' development and educational transition. This study utilizes data from the 10^{th} grade to 12^{th} grade and a follow-up survey after graduation.

Using these data over four years, I can analyze whether single-sex school affects students' decision on college enrollment and actual STEM major choice. To do this, I supplement our data with the college major information from Career Net (www.career.go.kr) provided by the Korean Research Institute for Vocational Education

& Training. I categorized each student's major (field or department) as STEM major based on college major list information in Career Net.

Students' data include scholastic ability test scores for Korean, English, and Math administered by the Seoul Metropolitan Office of Education and Research Information Service, which took place after the first semester of the school year. The tests are low stakes, but these tests represent a useful proxy for students' educational attainment as the test's contents are well aligned with the high school curriculum. I standardize students' test scores to have mean zero and standard deviation equal to be one for ease of interpretation. I also construct a measure of overall achievement by standardizing the sum of a student's performance in all subjects for 10^{th} grade[5].

By the end of the third wave of SELS, almost all those original 10^{th} graders (high school seniors) attend either two-year college or four-year college[6]. Because Korean students apply to specific majors (or department) for college admission, I can identify each student's college major with the information on first-year college students. I use the longitudinal information to examine the effect of single-sex schools on college attendance and the actual choice of STEM major. I utilize data of the total number of senior students and the number of those seniors who were enrolled in four-year college

5. After students choose their track at the end of 10^{th} grade, students who are in liberal arts-social science track takes type 1 math, and students who are in math-science track takes type 2 math which includes calculus, linear algebra, and probability and statistics. Students in math-science track also need to take an additional advanced math course. Thus, direct comparison of math test score among students in different tracks is not possible, so I analyze the impact of the single-sex school on test scores in 11^{th} and 12^{th} grade only using Korean and English test scores.

6 According to the Statistics Yearbook of Education by the Korean Educational Development Institute, college enrollment rate is 71.3% national wide. This is comparable to the college enrollment rate of our sample in SELS 2010, which is 70 %.

and in two-year college one year after their high school graduation to create college attendance, two-year college, and four-year college dummies, separately. I also included STEM major dummy to check whether enrollment in single-sex school (vs. co-ed school) has a long run impact on STEM outcomes.

The initial sample consists of students in the Seoul metropolitan area school. Because the lottery-based school assignment has only been applied to students in general high schools and public autonomous high school, I drop students in special purpose high schools and autonomous private high schools. The final sample consists of 65 high schools across 11 school districts, representing 30 percent of students in Seoul. Among these high schools, 24 are all-boys, 17 are all-girls, and 32 are coeducational.

Table 1.1 displays the characteristics of students and schools in our sample. As shown in Panel A, the standard measure of school resources including the number of class, class size, student to teacher ratio, and the number of teachers is generally comparable across the three types of schools. As expected, the share of female students by schools is 0 or 1 in single-sex schools and around 45 percent in coed schools. Interestingly, there exists a positive correlation between single-sex school and private school type. Although private schools and public schools are affected by a uniform set of education policies regulating the curriculum and teacher's qualification, private schools are relatively flexible regarding hiring teachers. Therefore, I need to note that teacher-related characteristics, which are not necessarily caused by single-sex school status, can differ between single-sex and co-ed schools. Single-sex males schools have fewer female teachers, 29 percent of teachers in all- boys schools are female compared to 58 percent in all-girls schools and 56 percent in coed schools.

Panel B provides the summary statistics on students' academic achievement at 10th grade. Each subject test scores are standardized to be mean of zero and standard deviation equal to be one. In general, female students earn higher test scores than male students in every subject and each type of school.

4. Empirical Strategy

Under the identifying assumption that within the given school district, students' allocation to schools is close to random, ordinary least square regression of outcomes of interest on single-sex schools generates the causal effect of attending single-sex schools versus coed schools. To measure the composite effect of single-sex schools on students' college enrollment and STEM choice, I estimate,

$$Y_{ijk} = \alpha + \beta Singlesex_{jk} + \gamma X_i + \phi_k + \varepsilon_{ijk} \tag{1.1}$$

Where Y_{ijk} represents the college enrollment and STEM major choice of student i assigned to school j in district k. The variable $singlesex_{jk}$ is an indicator variable that measures whether school j in district k is single-sex (versus coed) type. X_i is a vector of individual characteristics and household characteristics including an indicator for student living arrangement (e.g., both parents, single parents, and other relatives), number of siblings, birth order, household income, and an indicator for parents' education level. If the random assignment suggested by the institutional features and empirical test holds, these specifications should not differ substantially when pre-determined characteristics are controlled. The school district-level fixed effect, ϕ_k, is included to control for regional differences in education policy, which can affect students' academic outcomes. ε_{ijk} is the residual error component. Standard errors are clustered by the school to account for correlations among students within the same school. For each analysis, I estimated Eq. (1) for boys and girls separately to compare whether the sex composition of the schools affects the students’ outcomes differently by sex.

As a potential mechanism for single-sex school effects, I examine the extent to which the impact of single-sex school changes after controlling for the school level characteristics. Observable school characteristics, Z_{jk}, may affect students’ college enrollment and STEM major choice, and that may be correlated with the school’s single-sex status. Thus, it is essential to consider whether single-sex schools and coed schools may differ in teacher quality and other school characteristics. I extended the relationship of equation (1) to see whether the impact of single-sex schools remain after I control for school-level input;

$$Y_{ijk} = \alpha + \beta Singlesex_{jk} + \gamma X_i + \delta Z_{jk} + \phi_k + \varepsilon_{ijk} \qquad (1.2)$$

5. THE VALIDITY OF RESEARCH DESIGN

The random assignment of students into single-sex or coeducational schools should result in comparable socioeconomic conditions of students attending single-sex and coeducational schools within school districts. In this section, I use the first wave of SELS to test the validity of the research design by examining the balance of pre-determined students' socioeconomic background.

5.1. Balance of Predetermined Covariates

The purpose of a randomized evaluation is to ensure that the assignment of the treatment is orthogonal to other characteristics of the sample that may be correlated with students' academic outcomes. To verify the randomness of student assignment among high schools, I use first wave student- and parents- survey from the SELS to directly compare a series of students' socioeconomic characteristics that are all measured at the beginning of high school year. SELS provides rich information on students' family background including family structure, household income, and parents' education level. I use student's living arrangement, number of siblings, birth order, household income, Father's education level, and mother's education level as a measure of student's socioeconomic background. Each of these variables has been widely used as a proxy for student socioeconomic status that is correlated with student's educational outcomes (Sirin, 2005). Note that SELS data does not have a prior measure for students' academic achievement before entering high schools, so I am not able to control for the predetermined test score. Conditioning on district fixed effect, I regress each student and household characteristics on dummy indicating whether high school is single-sex (vs. coed) for boys and girls, separately. I expect that if students are randomly assigned to single-sex schools and coed schools, family background measures are not significantly associated with a student's enrollment in single-sex schools.

As shown in Table 1.2, I find no systematic difference in students' family background across school type. Student's living arrangement, family structure, and household income, and parents' education level are not significantly associated with the assignment to the single-sex schools versus coeducational schools for either boys or girls. Male students in single-sex schools are 4 percent more likely to live with both biological parents and 6 percent more likely to have a father with a bachelor's degree. Female students in single-sex schools are slightly less likely (1 percent) to live with grandparents and other relatives. These results reinforce the claim that the student distribution into either single-sex high schools or coeducational high schools is close to the random assignment. Nonetheless, I control for students' socioeconomic background in our main specifications.

5.2 The Difference in School Characteristics by School Types

Although the results in Table 1.2 present evidence that there is no significant difference in pre-assignment characteristics of students between student currently attending single-sex schools and their peers in co-ed schools, single-sex schools, and coed school can be differ in other important school characteristics that are found to be affect student academic achievement (Wayne and Youngs, 2003). In this analysis, I use the number of classrooms, student-teacher ratio, class size, a share of the student receiving free lunch, number of teachers, teacher's average education level, and teacher experience.

Table 1.3 shows estimates comparing the level of each school quality measure among all-boys, all-girls, and co-ed schools. Column (1) indicates that there is no systematic difference in the number of classrooms by school type. Interestingly, column (2) shows that pupil to teacher ratio is larger among students in all-boy schools and all-girls schools. Previous studies showed that the overall percentage of all estimates of teacher-pupil ratios that are statistically significant and positive effect on students' achievement is evenly balanced by those that are statistically significant and negative effect on students' achievement (Hanushek, 2003). Male students in all-boy schools are likely to have larger class size. Considering the Ill-known fact that class size reduction is positively correlated with higher test score (Jepsen and Rivkin, 2009, STAR project), this suggests that all-boy schools are slightly disadvantaged regarding class size. The results in column (4) to (7) show that there is no significant difference in a share of the student receiving free lunch, the number of teachers, teacher's average education level, and teacher experience among all-boy schools, all-girls schools, and coed schools. Overall, the results in Table 1.3 suggest that single-sex schools are not advantaged over coed schools regarding measured school characteristics. The results regarding school-related characteristics are expected because the Office of Education is strongly committed to imposing uniform and centralized set of education policies under HSEP. In sum, the results from Table 1.2 and Table 1.3 show that baseline student- and school-related characteristics are balanced between single-sex schools and coed schools.

6. RESULTS

6.1 Causal Effects of Single-sex Schools on College Attendance

I first examine the effect of single-sex schools on students' college enrollment after high school graduation. Table 1.4 presents between school estimates of attendance in single-sex schools for college enrollment rate for boys and girls, respectively. Any college represents a dummy variable whether students choose to go to college. College-2yr represents an indicator variable of whether students go to two-year college, and College-4yr represents an indicator of whether students go to a four-year university. Our first specification includes only school district fixed effects.

Panel A of Table 1.4 shows the estimates of school district fixed model for boys. In column (1) of Panel A, assignment to a single-sex school increases the male students' college attendance by 6.8 percent relative to coed school assignment. Male students from single-sex schools are 3.7 percent less likely to go to two-year college than male students in coed schools. However, none of these effects is statistically significant. The result from Column (5) in Panel A shows that male students from single-sex schools are statistically significantly 10 percent more likely to enroll in four-year university than their counterparts in coed school after high school graduation. In short, these suggest that single-sex high schools have a positive effect on college enrollment for male students, making students to attend a four-year college which has better school quality than a two-year college.

Turning to Panel B of Table 1.4 for girls, I find female students from all-girls schools show a significantly higher rate of college enrollment than their counterparts in coed schools. Assignment to all-girls schools increases college enrollment rate by 7 percent. From estimates in Column (3) and Column (5) of Panel B, I find that these effects are derived by 2.5 percent decrease in two-year college enrollment and 9.5 percent increase in four-year college enrollment. Similar to the results for boys, the advantage of all-girl schools over coed schools in sending female students to four-year college is substantial and statistically significant.

Our second and preferred specification, which controls for students' socioeconomic backgrounds, does not meaningfully affect the estimated results for boys and girls, respectively. This provides additional evidence that random assignment to high schools is valid in our data. For the remainder of the paper, I report results from our second specification that include school district fixed effect and controls for student characteristics.

6.2 Causal Effects of Single-sex Schools on STEM Major Choice

STEM outcomes are of particular interest considering women are substantially underrepresented in both STEM major and career despite the gender gap in schooling and academic achievement is small (Eisenkopf et al., 2015). Table 1.5 represents the impact of single-sex schools on STEM major choice in college. I examine the likelihood that students choose science, technology, engineering or math major, filed, or department after high school graduation. Similar to the regression analysis for college enrollment, I run school district fixed effect model controlling for student characteristics.

Panel A of Table 1.5 shows that single-sex school increase the probability of choosing STEM major in college by 7 percent for boys compared to male students in coed schools. In contrast, there is no significant difference in student's choice of STEM major in college for girls (Panel B of Table 1.5). I estimated the same specification conditional on college enrollment in column (3) and column (4). Similarly, the results show that boys from all-boy schools are statistically significantly around 9 percent more likely to major in the STEM field, but there is no difference in STEM choice for girls. I narrow the definition of STEM by removing nursing major and STEM-related education major to focus on the impact of single-sex schools on 'hard science'. In both cases, single-sex schools increase the likelihood that students choose STEM major only for boys. Specifically, male students in all-boy schools are 6.7 percent more likely to choose STEM major excluding nursing major, and 6.9 percent more likely to choose STEM major excluding both nursing major and STEM-related education majors, respectively. Again, I find no significant difference in STEM major choice for girls in single-sex schools and coed schools. (Appendix Table A. 1.)

7. EVIDENCE ON MECHANISM

7.1 Evaluating the Effects of Single-sex Schools

Single-sex schools and co-ed schools may differ in other important school characteristics that are found to affect student academic achievement (Wayne and Youngs, 2003). In this section, we examine possible dimensions that may affect students' college enrollment and STEM major choice. To do this, I control for school-level input to see whether the impact of single-sex schools remain after I condition on school-level observables. These include the number of classrooms, pupil-teacher ratio, class size, number of teachers, the fraction of female teacher within a grade, and an indicator for private (vs. public) establishment type. Column (1) uses no school controls. From Column (2) to Column (7) in Table1.6, I include on school characteristics at a time and Column (8) contains all the school characteristics together.

For male students, adding school-level inputs does not harm the effects of single-sex schools on the test score. For female students, a private school dummy seems to decrease positive effects of single-sex school on the test score, which could be explained by the correlation between private and single-sex school type and unobserved differences between public and private establishment. For example, private schools have greater autonomy in choosing their teachers (Sohn, 2016), which may have independent effects on the students' outcomes.

Some interesting patterns emerge if we focus on students' track choice and advanced math taking behavior in high schools. For both boys and girls, having more female teachers eliminates the effects of single-sex schools on STEM-related outcomes. Having more female teachers negatively affects the students' likelihood of choosing a STEM-related track and advanced math course for boys. On the other hands, higher female teacher ratio increases the probability of choosing a STEM-related track and advanced math course for girls. When I control all school characteristics together, the effects of single-sex schools on students' track choice and advanced math course taking are diminished and no longer statistically significant.

For college enrollment outcomes, the coefficients on single-sex schools for male students increase in magnitude when I control for the number of classrooms, pupil-teacher ratio, class size, and the number of teachers. Having more classroom, smaller teacher-pupil ratio, and smaller class size have a positive impact on male students' college enrollment and 4-year university enrollment, which consistent with the well-known fact that improved school environments are positively associated with better students' outcomes. For boys, the effects of single-sex schools on college enrollment, 2-year college enrollment, and 4-year university enrollment do not changes in terms of size and significance after all the school characteristics are controlled. For female students, the effects of single-sex schools on college enrollment and 4-year university drop in magnitude and no longer statistically significant when I control for an indicator of private school. Again, this could be explained by the correlation between private and single-sex school type and unobserved differences between public and private establishment.

In addition, I find that controlling school characteristics does not harm the coefficient of single-sex school on STEM major choice for male students. Again, adding private school dummy decrease the effect of single-sex school on STEM major choice for female students. When all the school characteristics are controlled together, attending single-sex school s increase the likelihood of choosing STEM major in college for boys. On the other hand, Female students in the single-sex schools are significantly less likely to choose STEM major in the college when I consider all the school-level inputs.

In sum, I find that school-level characteristics do not change the magnitude and significance of single-sex schooling on the college enrollment, and STEM major choice for boys. Conditioning private school dummy drops the sizes of the single-sex coefficient on students' outcomes for girls. Having a higher ratio of same-gender teachers are not associated with students' STEM major decision in a post-secondary institution.

8. CONCLUSION

In this study, I examine the causal effect of single-sex schools on a series of students' outcomes by exploiting the unique feature of education policy in Korea, in which students are assigned to single-sex or co-ed high schools by the lottery system. The analysis in this study shows that single-sex schools are causally linked with college enrollment, STEM outcomes for boys. In other words, graduates from all-boy schools are more likely to attend four-year college compared to their peers in co-ed schools. Attending all-boys school increases the likelihood for male students to choose a STEM major in the college. Although I find a positive impact of the single-sex school on female students' college enrollment, the estimates indicate that single-sex education is not statistically significantly associated with the STEM outcomes.

This paper carefully examines whether the single-sex schools and coed schools may differ not just in their gender composition but also along other dimensions that may affect achievement. I challenge this problem conditioning the observable school qualities to separate the net effects of exposure to same-gender peers from other school-level characteristics, even the distribution of students into high schools may be closed to random. The findings in this paper suggest that the positive effect of same-gender education for boys are robust after controlling for school-level characteristics.

Even though this paper identifies the positive effect of single-sex schooling in college enrollment and STEM major choice, the mechanism of how the gender composition of high school affects the post-secondary educational outcome remain unclear. In future research, it would be useful to extend this analysis by studying the effects of single-sex school on other important outcomes such as students' behavior, teacher's behavior, and teacher-student interaction.

Table 1.1: Summary Statistics

	All	Boys Only	Girls Only	Coed
Panel A. School-Level Characteristics				
Number of Classes	40.37	41.83	38.47	40.51
Class Size	35.38	36.01	35.98	34.15
Fraction Female Teachers	0.47	0.29	0.58	0.56
Fraction Female Students	0.44	0.00	1.00	0.44
Pupils per Teacher	16.70	17.10	17.13	15.88
Number of Teachers	80.66	83.04	78.00	80.36
Schools Founded by Private Entity	0.57	0.79	0.74	0.18
Observations (schools)	65	24	17	32
Panel B. Student-Level Characteristics				
Achievement: Male Student				
Korean	-0.19	-0.10		-0.41
Math	-0.04	0.04		-0.23
English	-0.13	-0.03		-0.37
Observation	2423	1719		704
Achievement: Female Student				
Korean	0.26		0.36	0.06
Math	0.05		0.12	-0.09
English	0.17		0.25	0.02
Observations	1898		1213	685

Notes: Tenth-grade high school students enrolled in Seoul. Subject test scores are standardized to have a mean equal to zero and standard deviation equal to one.

Table 1.2: Test of Balance in Students' Socioeconomic Status

Dep. Var.	Both Parents	Single Parents	Other Relative	Number of Sibling	Birth Order	Income
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Girls						
Girl only (vs. Coed)	0.0286	-0.0176	-0.0110*	-0.0188	-0.0223	0.0696
	(0.0190)	(0.0164)	(0.00577)	(0.0356)	(0.0348)	(0.079)
Observations	1,867	1,867	1,867	1,865	1,859	1,586
Panel B. Boys						
Boy only (vs. Coed)	0.0405*	-0.0362	-0.00428	-0.0529	-0.0441	0.0743
	(0.0210)	(0.0243)	(0.00344)	(0.0385)	(0.0387)	(0.0699)
Observations	2,151	2,151	2,151	2,148	2,147	1,853
Dep. Var.	High school-Father	College-Father	Degree-Father	High school-Mother	College-Mother	Degree-Mother
	(7)	(8)	(9)	(10)	(11)	(12)
Panel A. Girls						
Girl only (vs. Coed)	-0.0193	0.0178	0.0134	-0.0108	0.0457	-0.0148
	(0.0360)	(0.0294)	(0.0233)	(0.0341)	(0.0311)	(0.0147)
Observations	1,802	1,802	1,802	1,838	1,838	1,838
Panel B. Boys						
Boy only (vs. Coed)	-0.0590	0.0644*	0.0295	-0.0220	0.0464	0.00642
	(0.0356)	(0.0324)	(0.0231)	(0.0366)	(0.0364)	(0.0122)
Observations	2,056	2,056	2,056	2,095	2,095	2,095

Notes: Standard errors in parentheses are clustered at the school level. Each cell represents the regression coefficient of dependent variables on an indicator of single-sex school conditional on district fixed effects.

Table 1.3: Test of Balance in School-Level Characteristics

	Number of Classroom	Student-Teacher ratio	Class size	Free lunch	Number of Teacher	Teacher's education level	Teacher experience
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Boy only	2.929	1.183**	1.735*	-0.0312	5.633	-0.0206	0.743
	(2.821)	(0.469)	(0.845)	(0.023)	(4.775)	(0.107)	(2.258)
Girl only	-0.0545	1.272*	1.722	-0.033	2.012	-0.0602	-0.11
	(2.972)	(0.573)	(0.97)	(0.032)	(5.863)	(0.081)	(1.793)
Constant	33.27***	14.65***	32.63***	0.145***	68.05***	1.298***	14.15***
	(1.782)	(0.302)	(0.514)	(0.016)	(3.211)	(0.059)	(1.243)
N	65	65	65	65	65	65	65

Notes: Standard errors in parentheses are clustered at the school level. Each cell represents the regression coefficient of dependent variables on an indicator of single-sex school and district fixed effects.

Table 1.4: The Impact of Single-sex Schools on College Enrollment

	Any College (1)	Any College (2)	College-2yr (3)	College-2yr (4)	College-4yr (5)	College-4yr (6)
Panel A. Boys						
Single-sex (vs coed)	0.0683	0.0659	-0.0374	-0.0424	0.106***	0.108***
	(0.042)	(0.040)	(0.029)	(0.030)	(0.026)	(0.026)
N	2258	1992	2258	1992	2258	1992
Panel B. Girls						
Single-sex (vs coed)	0.0707*	0.0660*	-0.0245	-0.0294	0.0951***	0.0954***
	(0.039)	(0.038)	(0.031)	(0.033)	(0.031)	(0.032)
N	1901	1756	1901	1756	1901	1756
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Student Controls		Yes		Yes		Yes

Notes: Robust standard errors are clustered by school in parentheses; * p<0.10 ** p<0.05 *** p<0.01. All regressions include district fixed effects. Individual controls include an indicator for living arrangement (living with both parents, single parents, and grandparents or other relatives), number of the sibling, the birth order of child, and an indicator for at least one parents having a college degree or higher. Dependent variables in Column (1) and Column (2) represent an indicator of whether a student is enrolled in any types of college. Dependent variables in Column (3) and Column (4) represent an indicator of whether a student attend in vocational colleges. Dependent variables in Column (5) and Column (6) represent an indicator of whether a student attends in four-year universities.

Table 1.5: The Impact of Single-sex Schools on STEM Major Choice

	STEM (1)	STEM (2)	STEM (3)	STEM (4)
Panel A. Boys				
Single-sex (vs coed)	0.067**	0.068***	0.077*	0.087**
	(0.025)	(0.022)	(0.039)	(0.036)
N	2258	1992	1060	939
Panel B. Girls				
Single-sex (vs coed)	0.0296	0.015	0.016	-0.004
	(0.027)	(0.027)	(0.037)	(0.038)
N	1901	1756	1034	970
District FE	Yes	Yes	Yes	Yes
Student Controls		Yes		Yes

Notes: Robust standard errors are clustered by school in parentheses; * p<0.10 ** p<0.05 *** p<0.01. All regressions include district fixed effects. Individual controls include an indicator for living arrangement (living with both parents, single parents, and grandparents or other relatives), number of the sibling, the birth order of child, and an indicator for at least one parents having a college degree or higher. The dependent variable is an indicator of whether a high school graduate chooses STEM-related major, field or department at the college. Column (3) and Column (4) re-run the regression of STEM on single-sex indicator conditional on students' college enrollment.

Table 1.6: Effects of School Characteristics

School Controls	None	Number of Classroom	Pupil-Teacher ratio	Class Size	Number of Teacher	Female teacher ratio	Private	All
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
				Dep. Variable: College				
Panel A. Boys								
Single-sex	0.066	0.080**	0.081**	0.099**	0.079**	0.092*	0.056	0.087
	(0.040)	(0.037)	(0.038)	(0.04)	(0.037)	(0.05)	(0.060)	(0.061)
School		-0.005**	-0.011	-0.017*	-0.002**	0.081	0.016	
		(0.002)	(0.001)	(0.010)	(0.001)	(0.010)	(0.059)	
N	1992	1992	1992	1992	1992	1992	1992	1992
Panel B. Girls								
Single-sex	0.066*	0.070*	0.044	0.062	0.071*	0.043	0.015	-0.042
	(0.038)	(0.039)	(0.044)	(0.039)	(0.038)	(0.037)	(0.042)	(0.043)
School		0.004*	0.021	0.004	0.003	-0.242**	0.093**	
		(0.002)	(0.015)	(0.009)	(0.001)	(0.094)	(0.036)	
N	1756	1756	1756	1756	1756	1756	1756	1756
				Dep. Variable: 2yr College				
Panel A. Boys								
Single-sex	-0.042	-0.040	-0.037	-0.024	-0.039	-0.045	-0.029	-0.018
	(0.030)	(0.029)	(0.031)	(0.032)	(0.029)	(0.038)	(0.038)	(0.044)
School		-0.001	-0.004	-0.009	-0.001	-0.008	-0.022	
		(0.002)	(0.008)	(0.007)	(0.001)	(0.068)	(0.032)	
N	1992	1992	1992	1992	1992	1992	1992	1992
Panel B. Girls								
Single-sex	0.108***	0.120***	0.118***	0.123***	0.118***	0.137***	0.086**	0.105***
	(0.026)	(0.026)	(0.025)	(0.027)	(0.026)	(0.036)	(0.036)	(0.034)
School		-0.004***	-0.008*	-0.007	-0.0017**	0.090	0.038	
		(0.001)	(0.004)	(0.005)	(0.001)	(0.070)	(0.039)	
N	1756	1756	1756	1756	1756	1756	1756	1756
				Dep. Variable: 4yr University				
Panel A. Boys								
Single-sex	0.108***	0.120***	0.118***	0.123***	0.118***	0.137***	0.086**	0.105***
	(0.026)	(0.026)	(0.025)	(0.027)	(0.026)	(0.036)	(0.036)	(0.033)
School		-0.004***	-0.007*	-0.007	-0.002**	0.090	0.038	
		(0.001)	(0.003)	(0.005)	(0.0010)	(0.068)	(0.039)	
N	1992	1992	1992	1992	1992	1992	1992	1992
Panel B. Girls								
Single-sex	0.0954***	0.099***	0.079**	0.091***	0.099***	0.074**	0.0561	0.036
	(0.032)	(0.031)	(0.032)	(0.032)	(0.029)	(0.033)	(0.038)	(0.033)
School		0.004***	0.016	0.005	0.002**	-0.220**	0.072**	
		(0.001)	(0.010)	(0.006)	(0.001)	(0.082)	(0.030)	
N	1756	1756	1756	1756	1756	1756	1756	1756
District FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Student Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 1.6: Effects of School Characteristics (Continued.)

School Controls	None	Number of Classroom	Pupil-Teacher ratio	Class Size	Number of Teacher	Female teacher ratio	Private	All
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
				Dep. Variable: STEM major				
Panel A. Boys								
Single-sex	0.068***	0.072***	0.071***	0.082***	0.071***	0.074**	0.064**	0.081***
	(0.021)	(0.022)	(0.021)	(0.023)	(0.022)	(0.028)	(0.027)	(0.025)
School		-0.002	-0.003	-0.007	-0.000	0.017	0.007	
		(0.001)	(0.006)	(0.006)	(0.001)	(0.064)	(0.031)	
N	1992	1992	1992	1992	1992	1992	1992	1992
Panel B. Girls								
Single-sex	0.015	0.016	0.003	0.014	0.017	0.010	-0.013	-0.049*
	(0.027)	(0.028)	(0.034)	(0.032)	(0.028)	(0.030)	(0.020)	(0.025)
School		0.001	0.012	0.001	0.001	-0.051	0.051***	
		(0.001)	(0.010)	(0.007)	(0.001)	(0.081)	(0.019)	
N	1756	1756	1756	1756	1756	1756	1756	1756
District FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Student Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Robust standard errors are clustered by school in parentheses; * p<0.10 ** p<0.05 *** p<0.01. All regressions include district fixed effects. Individual controls include an indicator for living arrangement (living with both parents, single parents, and grandparents or other relatives), number of the sibling, the birth order of child, and an indicator for at least one parents having a college degree or higher. Column (1) replicates the coefficients of most preferred specification in Section 6. Column (2) to Column (7) represent the separate regression coefficients of dependent variables on the indicator of single-sex schools and each school controls. Column (8) includes all the school characteristics together.

Chapter 2: The Impact of Single-sex Schooling on Students' Academic Achievement

1 INTRODUCTION

In recent years, single-sex schooling has received increased attention. This is partly because several countries have been experimenting with single-sex classes within coeducational schools in an attempt to raise overall achievement. In the 2011-2012 school year, at least 506 public schools in the United States offered single-sex educational opportunities (NASSPE, 2012). The increase in single-sex education was enabled by the 2006 amendment in Title IX of the US Education Act, which allows more flexibility to school districts to provide single-sex education. Advocates view single-sex schooling will boost academic achievement by 1) eliminating distraction and harassment from other sex (Lobel et al., 2004; Meal et al., 2005), 2) addressing the optimal learning and managerial styles of girls and boys (Levy and Schlosser, 2001), or 3) pursuing non-stereotypical curricular and courses (Beaman et al., 2006; Einarsoon and Granstrom, 2002).

Despite a large body of literature on the effect of single-sex schooling on academic achievement, there is little well-designed research showing that single-sex education improves students' academic performance. Whether students' academic achievement is better in single-sex or coeducational schools is still an ongoing debate in many countries. Some believe that single-sex schooling enhances educational outcomes (Datnow and Hubbard 2002; Meal et al. 2005), while others believe such schools produce benefits for only a small segment of the population (Bracey, 2006) or reduce opportunities for cross-group contact (Balkin, 2002).

A fundamental issue underlying the disagreement on single-sex education is that it is an endogenous consequence of individual choice. In many countries, underlying observable and unobservable characteristics of students who choose single-sex school over coeducational schools are different in many aspects since most single-sex schools are private or religious, thus resulting in a selection problem. For this reason, there is relatively little convincing evidence on the effects of single-sex education despite extensive literature on single-sex school.

This paper examines the effects of single-sex schooling on students' academic achievements in high schools. I avoid the problem of nonrandom selection of students into schools using a unique institutional feature in Korea: assignment of students into high schools by computerized lottery. The high school assignment of middle school graduates in Seoul, which I will discuss below in more detail, offers an opportunity to examine the causal effect of single-sex schooling on students' academic achievements addressing concerns of endogenous sorting and differences in inputs that might be correlated with school type. Utilizing student-level administrative date from Seoul, Korea, I look at how gender peer composition affects students' academic outcomes including test scores and track choices within high schools.

I find that students benefit from attending single-sex school regarding academic achievement. Results suggest that assignment to a single-sex school increases male students' performance by 0.38 of a standard deviation, relative to coed school assignment. The estimated impact of attending single-sex school relative to attending coed school on female students' achievement increase to 0.3 of a standard deviation. These results are consistent in terms of size and magnitude if I estimate the impact of single-sex school on students' academic achievement by subjects. This positive effect of all-boys schools is consistent with the findings of the positive impact of all-boys schools on the choice of math-science tracks and the behavior of taking advanced math courses in high schools. In contrast, the findings of this paper demonstrate no significant effect of single-sex schools on female students' track choices and course-taking behaviors in high schools.

I also examine that interest in math subjects and a self-assessed understanding of math lectures account for the positive impact for male students attending single-sex schools. Male students in single-sex schools enhance their effort level in math by the end of the 12th grade. Besides, there is limited evidence that male students in all-boys schools increase their effort in academic activities and self-study time and reduce their time spent on leisure activities and sleep. Female students in single-sex schools, on the other hand, show less interest and understanding in math than their counterparts in the coed schools. Female students report a reduced effort level in math by the end of the 12th grade. Female students in all-girls schools spend more time on self-study and less time on leisure activities than their counterparts in coed schools.

The remainder of the paper is organized as follows. Section 2 presents information on the educational system and students' assignment policy adopted in Seoul, Korea. Section 3 describes the data and variables utilized in this paper, and Section 4 describes our empirical strategy. In Section 5, I present the results on the validity of the research design. I show estimates of single-sex schooling on academic achievements in Section 6. I discuss the mechanism behind my main findings through evidence from survey data on the students' interest, understanding, efforts, and school-level inputs in Section 7. Section 8 provides a conclusion of the study.

2 BACKGROUND

2.1 The Education System of Korea

In Korea, all students attend nine years of compulsory schooling: six years of primary education followed by three years of middle (lower-secondary) schooling. Graduates of middle schools or the equivalent can then pursue additional education at high schools. High schools are divided into general academic schools, vocational schools, and merit schools, which are foreign language high schools, science high schools, art high schools, and private autonomous high schools[7]. As of 2010, about 75 percent of Korean high school students attended general academic high schools (Statistical

[7] Vocational high schools provide education for students who want to enter a specific profession. They offer general secondary education in the first year, with specialized courses in the fields of agriculture, industry, commerce, and so on in the final two years. Merit high schools are established to provide elite education for talented students in a variety of fields. Even though these schools are located within HSEP school district, they are not subjected to the HSEP and are operated independently regarding school budget, curriculum, and so on.

Yearbook of Education). General academic high schools provide advanced general education as well as elective courses, which students select based on their intended university admission.

Admission to general high schools differs across school systems. Students in major metro areas, designated “equalization areas,” are placed in senior high schools based on a lottery system, while schools in other regions admit students based on the students’ prior school records and school-administered entrance examination. Vocational and special-purpose high school applicants select their school of choice and are accepted based on that school's entrance exam and their middle school academic records.

One year after high school entry, students choose their academic track regardless of their school type. Most schools provide a math-science track and a liberal arts-social science track, except for art, foreign language, and science schools. Students focus on advanced courses within a given track; this choice is crucial in Korea. When students apply for college admission, those who choose a math-science track mostly apply to STEM-related majors, fields, or departments. Students in liberal arts tracks, however, apply to liberal arts or social science major.

If a student chooses a math-science track, the College Scholastic Ability Test (CSAT) consists of Korean, English, type 2 mathematics, and science subjects including physics, chemistry, geology, and biology. Students in the liberal arts-social science track take a CSAT exam containing Korean, English, type 1 mathematics, and social science subjects including political science, economics, geography, philosophy, and more.

Students are free to choose their academic track; past test scores and student characteristics are not considered by schools or teachers when students decide on a track choice. There are no minimum or maximum slots available for the students within each track. Changing the academic track is rare because students apply to a postsecondary institution in 12th grade, and it is difficult to catch up on the necessary coursework. Enrollment in STEM major (fields or departments) at postsecondary institutions requires advanced math and science courses. Therefore, if single-sex schooling has persistent effects into high school year, the choice of academic track in high schools has a substantial long-term impact on a student's future career.

2.2 High School Assignment in Seoul

Before 1974, Korean high schools could choose their students based on the students' scores on the entrance examinations administered by individual high schools, resulting in clustering by family background and substantial differences between schools in students' academic performances (Park et al. 2013). The High School Equalization Policy (HSEP) was designed to alleviate inequality among high schools and prevent excessive competition for acceptance into the elite high schools, which caused overspending on private tutors and institutes[8]. The HSEP was first introduced in Seoul and Busan, the two largest metropolitan areas in Korea. The policy was then expanded to

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8. Families spent $200 per month per student for private tutoring on average in 2008. This amount indicates a 0.2 percent point increase in private tutoring expenditure compared to the previous year.

cover the three next largest metropolitan regions of Daegu, Inchon, and Kwangju in 1975. As of 2001, the HSEP covered all seven metropolitan areas and 11 provincial cities (Kim et al., 2008).

The HSEP created a natural experiment in which middle school students are randomly assigned to high schools within their school districts of residence by a computerized lottery system. Student mixing in the HSEP areas is quite thorough since the area of a typical enrollment zone is rather large. For example, Seoul, with its over 10 million habitants, is divided into 11 enrollment zones.

In 2010, the Office of Education at Seoul Metropolitan Area introduced the modified version of the equalization polity to respond to growing concerns for limited school choice, allowing students to list up to four schools that they prefer. There are three rounds of admissions to high schools in Seoul. In the first round, which occurs in the spring semester, the application is determined through an application process. Students can apply to one of merit high schools and vocational high schools. Schools select students based on their academic performance and recommendations from principals and teachers from middle schools. Once selected, students must attend the school that they are admitted. The second round consists of a lottery for general high schools and autonomous public high schools. Students can list preferences up to four general high schools within their school districts. The lottery provides entry into the general high schools. Finally, if students fail to enter any of these schools they listed in the second round, students are randomly assigned to high schools with vacant seats in their school districts.

The assignment of students to general high schools is administered by the Office of Education in the Seoul metropolitan area. While the detailed algorithm of computerized lottery system is confidential, the Office of Education provides general procedure on student assignment. First, the Office of Education determines the number of total seats available in all high schools in their region. Second, middle school graduates send their high school application to the Regional Office of Education. Third, the computer program allocates high school applicants to the set of relevant high schools. Up to this stage, student's academic records at the middle school are not used in the actual assignment process.

Once qualified, only the individual’s residential address as of the last academic year in middle school is utilized for the lottery[9]. Therefore, if the student wants to take part in a high school lottery in a different school district, his/her family has to move to the new district before the last year of middle school starts. The high school assignment is applied regardless of whether schools are coeducational or single-sex as well as public or private.

One can think that students might move their residence to a new school district for any reason, including their dissatisfaction with the original school assignment. This

9 An academic year runs from March to February of the following year. The high school assignment is based on the applicant's address as of August in the last academic year during middle school. Not only the academic records but the location of middle school that high school applicant attended is not considered for the lottery system.

seems unlikely because students are subject to another random assignment in the new school district. In other words, there is no guarantee that students can choose either single-sex school or coeducational school with certainty even if they have a specific preference about it. Discussing possibility of non-compliance, Park et al. (2013) and Sohn (2016) showed that the actual percentage of households moving into a different school district during the periods of high school application is very small and concluded that non-compliance is not likely to cause severe distortions in the estimates of the causal effect of single-sex schools in Seoul. Also, there have been continuous regulation changes that restrict students' school transferring within/between school districts to avoid Tiebout sorting [10].

Private schools in Seoul are also subject to the high school assignment process. Students attending private and public schools do not differ significantly in terms of socioeconomic background (Park et al., 2013, autonomous). Both public schools and private schools in Korea have been made homogeneous by uniform and centralized set of education policies regulating the curriculum and teacher's qualification under HSEP. The Ministry of Education provides a standardized national curriculum, based on either designated or certified textbooks. The central and local government fully funds teacher salaries and operating expenditure for public schools and private schools as well as

[10] School transferring is available if 1) a student moves from another metropolitan area/province, 2) a student is a victim of school violence, or if 3) a student has trouble commuting due to a severe illness. If a student falls in one of these three situations, they are randomly assigned to schools with a vacancy within the school district.

single-sex schools and coed schools. All the general high schools in Korea impose the same amount of tuition for students.

Private schools are founded and owned by a private entity and have rights to select teachers. Central and local governments govern teacher selection and appointment into public schools. Public school teachers need to meet a qualification test to become a teacher and are all public employees of the government (Sohn, 2016). On the other hands, each private school is in charge of the selection and appointment of teachers once they meet the qualification required by the government (Kim et al., 2008).

3 DATA

Our primary data set is the Seoul Education Longitudinal Study of 2010 (SELS 2010), which surveyed 10th-grade students, parents, school, and teacher in 2010. Data are available through 12th grade, with a follow-up survey after high school graduation on postsecondary outcomes.

There are 235 academic high schools in Seoul, excluding one high school that is operated by the central government and five art and athletic high schools. Students in the 10th-grade panel were sampled by stratified two-stage cluster sample design. First, 60 general high schools were randomly chosen from the population of 198 general high schools, 13 autonomous high schools were randomly selected from the entire 21 autonomous high schools, and all 10 special purpose high schools are surveyed. Second, two classrooms were then drawn randomly within the sample school. The base line sample consists of 5,240 of the 6,456 targeted students in 2010.

In the 2010 baseline survey, SELS collected a variety of information on students' academic achievements, track choice, attitude towards study, interest in specific subjects, students' demographic characteristics, family backgrounds characteristics, teacher characteristics, and school characteristics. SELS re-interviewed respondents in the original sample to obtain information on students' development and educational transition.

Students' data include scholastic ability test scores for Korean, English, and Math administered by the Seoul Metropolitan Office of Education and Research Information Service, which took place after the first semester of the school year. The tests are low stakes, but these tests represent a useful proxy for students' educational attainment as the test's contents are well aligned with the high school curriculum. I standardize students' test scores to have mean zero and standard deviation equal to be one for ease of interpretation. I also construct a measure of overall achievement by standardizing the sum of a student's performance in all subjects for 10th grade[11].

STEM outcomes are of particular interest since although the gender gap in math achievement in secondary education is small, women are substantially underrepresented

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[11]. After students choose their track at the end of 10th grade, students who are in liberal arts-social science track takes type 1 math, and students who are in math-science track takes type 2 math which includes calculus, linear algebra, and probability and statistics. Students in math-science track also need to take an additional advanced math course. Thus, direct comparison of math test score among students in different tracks is not possible, so I analyze the impact of the single-sex school on test scores in 11th and 12th grade only using Korean and English test scores.

in both STEM major and career. One major question in this study is whether single-sex schools and coed schools differentially affect students' academic track choice in high schools, which is associated with future academic career and employment. I created an indicator variable whether a student chooses a math-science track. To measure the impact of single-sex schools on students' course-taking behavior, I also create an indicator variable that is one if a student takes advanced math courses and 0 otherwise.

The initial sample consists of students in the Seoul metropolitan area school. Because the lottery-based school assignment has only been applied to students in general high schools and public autonomous high school, I drop students in special purpose high schools and autonomous private high schools. The final sample consists of 65 high schools across 11 school districts, representing 30 percent of students in Seoul. Among these high schools, 24 are all-boys, 17 are all-girls, and 32 are coeducational.

Table 2.1 displays the characteristics of students and schools in our sample. As shown in Panel A, the standard measure of school resources including the number of class, class size, student to teacher ratio, and the number of teachers is generally comparable across the three types of schools. As expected, the share of female students by schools is 0 or 1 in single-sex schools and around 45 percent in coed schools. Interestingly, there exists a positive correlation between single-sex school and private school type. Although private schools and public schools are affected by a uniform set of education policies regulating the curriculum and teacher's qualification, private schools are relatively flexible regarding hiring teachers. Therefore, I need to note that teacher-related characteristics, which are not necessarily caused by single-sex school status, can differ between single-sex and co-ed schools. Single-sex males schools have fewer female teachers, 29 percent of teachers in all- boys schools are female compared to 58 percent in all-girls schools and 56 percent in coed schools.

Panel B provides the summary statistics on students' academic achievement at 10^{th} grade. Each subject test scores are standardized to be mean of zero and standard deviation equal to be one. In general, female students earn higher test scores than male students in every subject and each type of school.

4 Empirical Strategy

Under the identifying assumption that within the given school district, students' allocation to schools is close to random, ordinary least square regression of outcomes of interest on single-sex schools generates the causal effect of attending single-sex schools versus coed schools. To measure the composite effect of single-sex schools on students' academic achievement in high schools, I estimate,

$$Y_{ijk} = \alpha + \beta Singlesex_{jk} + \gamma X_i + \phi_k + \varepsilon_{ijk} \qquad (2.1)$$

Where Y_{ijk} represents the test scores of a student i assigned to school j in district k. The variable $singlesex_{jk}$ is an indicator variable that measures whether school j in district k is single-sex (versus coed) type. X_i is a vector of individual characteristics and household characteristics including an indicator for student living arrangement (e.g., both parents, single parent, and other relatives), number of siblings, birth order, household income, and an indicator for parents' education level. If the random assignment suggested by the institutional features and empirical test holds, these specifications should not differ substantially when pre-determined characteristics are controlled. The school district-level fixed effect, ϕ_k, is included to control for regional differences in education policy, which can affect students' academic outcomes. ε_{ijk} is the residual error component. Standard errors are clustered by the school to account for correlations among students within the same school. For each analysis, I estimated Eq. (2.1) for boys and girls separately to compare whether the sex composition of the schools affects the students' outcomes differently by sex.

5 THE VALIDITY OF RESEARCH DESIGN

The random assignment of students into single-sex or coeducational schools should result in comparable socioeconomic conditions of students attending single-sex and coeducational schools within school districts. In this section, I use the first wave of SELS to test the validity of the research design by examining the balance of pre-determined students' socioeconomic background.

5.1 Balance of Predetermined Covariates

The purpose of a randomized evaluation is to ensure that the assignment of the treatment is orthogonal to other characteristics of the sample that may be correlated with students' academic outcomes. To verify the randomness of student assignment among high schools, I use first wave student- and parents- survey from the SELS to directly compare a series of students' socioeconomic characteristics that are all measured at the beginning of high school year. SELS provides rich information on students' family background including family structure, household income, and parents' education level. I use student's living arrangement, number of siblings, birth order, household income, Father's education level, and mother's education level as a measure of student's socioeconomic background. Each of these variables has been widely used as a proxy for student socioeconomic status that is correlated with student's educational outcomes (Sirin, 2005). Note that SELS data does not have a prior measure for students' academic achievement before entering high schools, so I am not able to control for the predetermined test score. Conditioning on district fixed effect, I regress each student and household characteristics on dummy indicating whether high school is single-sex (vs. coed) for boys and girls, separately. I expect that if students are randomly assigned to single-sex schools and coed schools, family background measures are not significantly associated with a student's enrollment in single-sex schools.

As shown in Table 2.2, I find no systematic difference in students' family background across school type. Student's living arrangement, family structure, and household income, and parents' education level are not significantly associated with the assignment to the single-sex schools versus coeducational schools for either boys or girls. Male students in single-sex schools are 4 percent more likely to live with both biological parents and 6 percent more likely to have a father with a bachelor's degree. Female students in single-sex schools are slightly less likely (1 percent) to live with grandparents and other relatives. (Estimate the propensity score). These results reinforce the claim that the student distribution into either single-sex high schools or coeducational high schools is close to the random assignment. Nonetheless, I control for students' socioeconomic background in our main specifications.

5.2 The Difference in School Characteristics by School Types

Although the results in Table 2.2 present evidence that there is no significant difference in pre-assignment characteristics of students between student currently attending single-sex schools and their peers in co-ed schools, single-sex schools, and co-ed school can be differ in other important school characteristics that are found to be affect student academic achievement (Wayne and Youngs, 2003). In this analysis, I use the number of classrooms, student-teacher ratio, class size, a share of the student receiving free lunch, number of teachers, teacher's average education level, and teacher experience.

Table 2.3 shows estimates comparing the level of each school quality measure among all-boys, all-girls, and co-ed schools. Column (1) indicates that there is no systematic difference in the number of classrooms by school type. Interestingly, column (2) shows that pupil to teacher ratio is larger among students in all-boy schools and all-girls schools. Previous studies showed that the overall percentage of all estimates of teacher-pupil ratios that are statistically significant and positive effect on students' achievement is evenly balanced by those that are statistically significant and negative effect on students' achievement (Hanushek, 2003). Male students in all-boy schools are likely to have larger class size. Considering the Ill-known fact that class size reduction is positively correlated with higher test score (Jepsen and Rivkin, 2009, STAR project), this suggests that all-boy schools are slightly disadvantaged regarding class size. The results in column (4) to (7) show that there is no significant difference in a share of the student receiving free lunch, the number of teachers, teacher's average education level, and teacher experience among all-boy schools, all-girls schools, and coed schools. Overall, the results in Table 2.3 suggest that single-sex schools are not advantaged over coed schools regarding measured school characteristics. The results regarding school-related characteristics are expected because the Office of Education is strongly committed to imposing uniform and centralized set of education policies under HSEP. In sum, the results from Table 2.2 and Table 2.3 show that baseline student- and school-related characteristics are balanced between single-sex schools and coed schools.

6 RESULTS

6.1 Causal Effects of Single-sex Schools on Test Scores

I first compare the outcomes of students in single-sex schools to those of their counterparts in coed schools to examine the impact of single-sex schools on students' academic achievement. I standardized students' test scores to have mean zero and standard deviation equal to be one for ease of interpretation. The results in Table 2.4 represent the causal effect of single-sex school on test score in 10^{th} grade by gender.

The result in Column (1) of Panel A shows that assignment to single-sex school increase male students' achievement by a statistically significant 0.38 of a standard deviation, relative to coed school assignment. Attending all-girls schools also statistically significantly increase the test score of female students by 0.27 a standard deviation compared to that of their counterparts in coed school. In other words, I find positive effects of all-boys schools and all-girls schools on students' achievement.

Next, I investigate whether the impact of gender-segregated education is driven by the effects on achievement in specific subject areas. I examine students' performance in Korean, English, and Mathematics test, separately. As shown in Column (2) to Column (4) in Panel A, male students in all-boy schools outperform their counterparts in coed schools, scoring between 0.3 and 0.37 of a standard deviation higher than boys in coed schools. Attending all-girl schools increases female students' test score by 0.33 of a standard deviation for Korean and by 0.2 of a standard deviation for Mathematics, relative to attending coed schools. I found no significant difference between female students attending all-girl schools and those attending coed schools in English test score (Column (2) to Column (4) in Panel B).

Interestingly, I find different results compared with the findings presented in Lee et al. (2014). For the male sample, the estimated single-sex effects in Lee at al. (2014) are between 0.17 and 0.28 of a standard deviation. The corresponding effect estimates I find are about 25 to 30 percent higher than those reported in the previous study. Second, effect estimates for the female sample in the earlier study are not statistically significant and close to zero. The estimates derived in this study, on the other hand, are 0.33 of a standard deviation for Korean, 0.2 of standard deviation for Mathematics and 0.2 of a standard deviation for English, respectively.

6.2 Causal Effects of Single-sex Schools on High School Track Choice

Given that the Type 2 math test score is required for application to STEM major in college, it is useful to examine whether students in single-sex schools and coed schools differ in the degree to which they choose academic track; math-science track versus liberal art-social science track. Table 2.5 presents the results of the linear probability model that examine the likelihood of students to select math-science track relative to liberal art-social science track. These specifications include school district fixed effect and controls for student characteristics.

Column (1) of Table 2.5 presents the results of the effects of single-sex schools on student's math-science track choice at the end of 10^{th} grade. The result in Panel A shows that male students in all-boy schools are more likely to take math-science track than male students in coed schools. Specifically, the probability of choosing math-science track among male students in all-boy schools are around 9 percent higher than those among their counterparts in coed schools. Conversely, I find no statistically significant relationship in math-science track choice behavior among female students between single-sex schools and coed schools.

Once a student chooses their academic track, they focus on the advanced course within their track. Students who choose math-science track take advanced math courses such as calculus, probability and statistics, and so on. The estimates in Column (2) of Table 2.5 show the impact of single-sex education on students' advanced math course taking. The results in Panel A shows that male students in all-boy schools are statistically significantly 8 percent more likely to choose advanced math courses compared to male students in coed schools. However, I find no significant difference in advanced math course taking among female students between single-sex schools and coed schools. The magnitude of effects is expected and consistent with those in Column (1) considering only students who choose math-science track take the advanced math courses. In sum, the results in Table 2.5 show that assignment to single-sex schools substantially increases the odds of preparation in STEM study in high schools only for boys.

7 EVIDENCE ON MECHANISM

My findings show that both male students and female students in single-sex schools outperform their counterparts in coed schools regarding total test score and subject test score. However, the positive effects of single-sex schools on academic achievements are not transferred to STEM-related outcomes for female students. I investigate several possible mechanisms that can drive these results.

7.1 Effects on Students' Belief in Math

According to the ‘stereotype threat’ hypothesis (Steele, 1997), females are more likely to conform to female-specific stereotypes in the presence of males, since they sense gender-specific expectation that they do not want to disappoint. Single-sex schooling has been hypothesized to affect several attitudinal and behavioral outcomes such as self-esteem and interests (Hayes et al., 2011). I tested whether students' interests and understanding in math are differentially affected by the gender composition of their peers in high schools. Specifically, students are classified as ‘Interest in math' if they strongly agree or agree with the statement "I am interested in a math course.". Students are classified as ‘Understand math' if they strongly agree or agree with the statement "I fully understand course material in math class.". I run a linear probability model that regress each outcome variables on an indicator for single-sex school conditional on school district fixed effects and students’ characteristics.

As shown in Panel A of Table 2.6, male students attending all-boy schools show higher levels of interests and understanding in mathematics than their counterparts attending coed schools. In 10^{th} grade, male students in single-sex schools are 7 percent more likely to be interested in math and 13 percent more likely to understand lecture than their counterparts within coed schools, respectively. Female students in all-girl schools, on the other hands, show no significant differences in interest in math compared to their peers in coed schools. The result indicates that all-girl schools are negatively associated with student’s self-assessed understanding of math lecture (Panel B of Table 2.6). In the previous section, I find that both male and female students outperform their counterparts in coed schools regarding the total test score and math test score, but only male students in the all-boys schools have higher odds of taking math-science track than their counterparts in coed schools at the end of 10th grade. The evidence I find suggests that single-sex schools enhance male students' confidence in STEM-related field by increasing students' interest and self-evaluated understanding in math subject, resulting more male students in single-sex schools to delve into the math-science track.

In addition, I examine whether the students' belief in math changes over time. I find that single-sex schooling has no significant impact on interest and understanding of math for the boy in 11th grade. In contrast, it reduces female students' interest in math by 6 percent and understanding in math by 5.5 percent, respectively and the estimates for female students are statistically significant. The results indicate that the single-sex schooling has positively associated with the male students' interest and understanding in math, while it has a negative impact on female student's interest and understanding in math in 12th grade. In sum, the findings suggest that the consistent lack of interest and understanding in math could lead under-investment in math for female students in the high schools.

7.2 Effects on Students' Effort

To test whether students' effort responds to the gender composition of their peers, I create a summary measure of effort using students' responses to several survey questions. Specifically, I sum students' responses to five individual survey questions that ask students to access whether they come to class prepared, are concentrate on lecture, study class material in advance, review after class and do homework thoroughly. I standardized this composite effort index to have a mean equal to zero and a standard deviation to be one.

As shown in Panel A of Table 2.7, single-sex schooling has a positive impact on male students' effort. Attending all-boys schools increase the students' effort by 0.13 of a standard deviation for 10th grade, 0.21 of a standard deviation for 11th grade, and 0.145 of a standard deviation for 12th grade, respectively. Estimated effects for 11th-and 12th-grade are statistically significant. I also find strong evidence that single-sex schooling systematically increases female students' effort. Specifically, attending all-girls schools increases the students' effort by 0.19 0.13 of a standard deviation for 10th grade, 0.09 of a standard deviation for 11th grade, and 0.18 of a standard deviation for 12th grade, respectively (Panel B of Table 2.7).

Then, I further investigate students' effort in math subject (Table 2.8). Male students in all-boys schools put more effort on math by 0.08 of a standard deviation for 10th grade, by 0.18 of a standard deviation for 11th grade and by 0.16 of a standard deviation for 12th grade than their counterparts in the coed schools, respectively. Estimated effects for 11th- and 12th- grade are statistically significant. Female students in all- girls students put significantly more effort on math by 0.3 of a standard deviation in 10th grade and by 0.15 of a standard deviation in 11th grade. However, they substantially increase their efforts in Korean and English than their counterparts in coed school in 12th grade. There is no significant difference in math effort level at the end of high school year. In sum, the results suggest that boys in single-sex schools report higher effort level in math as they are more exposed to the single-sex school, whereas the positive impact of all-girls schools on effort level of female students attenuates.

8 CONCLUSION

In this study, I examine the casual effect of single-sex schools on a series of students' outcomes by exploiting the unique feature of education policy in Korea, in which students are assigned to single-sex or coed high schools by a lottery system. Main findings of this paper show that single-sex schools are causally linked with improved academic achievement for both boys and girls. In other words, attending all-boys schools or all-girls schools, rather than attending co-ed schools, is significantly associated with higher scores on Korean, math, and English test. Although the previous literature showed positive associations of all-girls schools with education outcome related to mathematics, I cannot find the significant effects of all-girls schools on such outcomes.

I investigated several channels to account for the differential effects of single-sex schooling on students' outcome by gender. My findings suggest that single-sex schools increase the likelihood of choosing a math-science track and taking an advanced math course for male students through enhancing male students' interest and understanding in math and increasing students' effort and time spent to academic activities. In contrast, single-sex schooling is negatively associated with female students' interest and understanding of math at the beginning of the high school year.

There are caveats we need to consider when we interpret the results. While the assignments of students to high schools are close to random, the distribution of teacher is not. I carefully examine whether the single-sex schools and coed schools have different school quality using the best measure that I can obtain from our data set. The results show that single-sex schools are not significantly different from coed school in terms of the key measures of school characteristics: student-teacher ratio, class size, number of classrooms, the fraction of free lunch taker, the fraction of experienced teacher and so on. I note that single-sex schools and coed schools are different in other schools/teacher characteristics that I cannot take into account using the data we have.

In addition, I cannot fully determine what underlying factors drive better academic achievement for either single-sex school or coed school or both due to the data limitation. For example, if a coed school has single-sex classes, the causal effect of single-sex school on student performance will be biased. There is also the possibility that interaction with same-sex teachers has affected the student outcome (Bettinger and Long, 2005; Dee, 2007). I suggest that future studies look at this issue more systematically.

Table 2.1: Summary Statistics

	All	Boys Only	Girls Only	Coed
Panel A. School-Level Characteristics				
Number of Classes	40.37	41.83	38.47	40.51
Class Size	35.38	36.01	35.98	34.15
Fraction Female Teachers	0.47	0.29	0.58	0.56
Fraction Female Students	0.44	0.00	1.00	0.44
Pupils per Teacher	16.70	17.10	17.13	15.88
Number of Teachers	80.66	83.04	78.00	80.36
Schools Founded by Private Entity	0.57	0.79	0.74	0.18
Observations (schools)	65	24	17	32
Panel B. Student-Level Characteristics				
Achievement: Male Student				
Korean	-0.19	-0.10		-0.41
Math	-0.04	0.04		-0.23
English	-0.13	-0.03		-0.37
Observation	2423	1719		704
Achievement: Female Student				
Korean	0.26		0.36	0.06
Math	0.05		0.12	-0.09
English	0.17		0.25	0.02
Observations	1898		1213	685

Notes: Tenth-grade high school students enrolled in Seoul. Subject test scores are standardized to have a mean equal to zero and standard deviation equal to one.

Table 2.2: Test of Balance in Students' Socioeconomic Status

Dep. Var.	Both Parents	Single Parents	Other Relative	Number of Sibling	Birth Order	Income
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Girls						
Girl only (vs. Coed)	0.029	-0.018	-0.011*	-0.018	-0.022	0.070
	(0.019)	(0.016)	(0.006)	(0.036)	(0.035)	(0.080)
Observations	1,867	1,867	1,867	1,865	1,859	1,586
Panel B. Boys						
Boy only (vs. Coed)	0.041*	-0.036	-0.004	-0.053	-0.044	0.074
	(0.021)	(0.024)	(0.003)	(0.039)	(0.039)	(0.070)
Observations	2,151	2,151	2,151	2,148	2,147	1,853
Dep. Var.	High school-Father	College-Father	Degree-Father	High school-Mother	College-Mother	Degree-Mother
	(7)	(8)	(9)	(10)	(11)	(12)
Panel A. Girls						
Girl only (vs. Coed)	-0.019	0.018	0.013	-0.011	0.046	-0.015
	(0.036)	(0.029)	(0.023)	(0.034)	(0.031)	(0.015)
Observations	1,802	1,802	1,802	1,838	1,838	1,838
Panel B. Boys						
Boy only (vs. Coed)	-0.0590	0.064*	0.030	-0.022	0.046	0.006
	(0.036)	(0.032)	(0.023)	(0.037)	(0.036)	(0.012)
Observations	2,056	2,056	2,056	2,095	2,095	2,095

Notes: Standard errors in parentheses are clustered at the school level. Each cell represents the regression coefficient of dependent variables on an indicator of single-sex school conditional on district fixed effects.

Table 2.3: Test of Balance in School-Level Characteristics

	Number of Classroom	Student-Teacher ratio	Class size	Free lunch	Number of Teacher	Teacher's education level	Teacher experience
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Boy only	2.929	1.183**	1.735*	-0.0312	5.633	-0.0206	0.743
	(2.821)	(0.469)	(0.845)	(0.023)	(4.775)	(0.107)	(2.258)
Girl only	-0.0545	1.272*	1.722	-0.033	2.012	-0.0602	-0.11
	(2.972)	(0.573)	(0.97)	(0.032)	(5.863)	(0.081)	(1.793)
Constant	33.27***	14.65***	32.63***	0.145***	68.05***	1.298***	14.15***
	(1.782)	(0.302)	(0.514)	(0.016)	(3.211)	(0.059)	(1.243)
N	65	65	65	65	65	65	65

Notes: Standard errors in parentheses are clustered at the school level. Each cell represents the regression coefficient of dependent variables on an indicator of single-sex school and district fixed effects.

Table 2.4: The Impact of Single-Sex Schools on Students' Achievement

	Total (1)	Total (2)	Korean (3)	Korean (4)	Math (5)	Math (5)	English (6)	English (6)
Panel A. Boys								
Single-sex (vs coed)	0.382***	0.382***	0.359***	0.330***	0.296***	0.305***	0.388***	0.374***
	(0.109)	(0.110)	(0.099)	(0.100)	(0.096)	(0.098)	(0.112)	(0.113)
N	2253	1988	2237	1975	2110	1866	2236	1975
Panel B. Girls								
Single-sex (vs coed)	0.299**	0.267**	0.344***	0.326***	0.222**	0.191*	0.228*	0.197
	(0.124)	(0.117)	(0.117)	(0.110)	(0.108)	(0.105)	(0.130)	(0.120)
N	1895	1751	1887	1743	1809	1675	1889	1745
District FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Student Controls		Yes		Yes		Yes		Yes

Notes: Robust standard errors are clustered by school in parentheses; * p<0.10 ** p<0.05 *** p<0.01. All regressions include district fixed effects. Individual controls include an indicator for living arrangement (living with both parents, single parents, and grandparents or other relatives), number of the sibling, the birth order of child, and an indicator for at least one parents having a college degree or higher. Dependent variables in column (1)-(2) represent the sum of Korean, Math, English test scores, standardized to have a mean zero and standard deviation equal to one. Dependent variables in column (3)-(6) represent each subject test score of Korean, Math, and English, standardized to have a mean zero and standard deviation equal to one.

Table 2.5: The Impact of Single-sex Schools on High School Track Choice

	Math-Science Track	Math-Science Track	Advanced Math	Advanced Math
	(1)	(2)	(3)	(4)
Panel A. Boys				
Single-sex (vs coed)	0.088***	0.087**	0.081**	0.081**
	(0.030)	(0.033)	(0.031)	(0.033)
N	2057	1847	2057	1847
Panel B. Girls				
Single-sex (vs coed)	0.009	-0.007	0.022	0.005
	(0.028)	(0.029)	(0.026)	(0.027)
N	1828	1692	1828	1692
District FE	Yes	Yes	Yes	Yes
Student Controls		Yes		Yes

Notes: Robust standard errors are clustered by school in parentheses; * p<0.10 ** p<0.05 *** p<0.01. All regressions include district fixed effects. Individual controls include an indicator for living arrangement (living with both parents, single parents, and grandparents or other relatives), number of the sibling, the birth order of child, and an indicator for at least one parents having a college degree or higher. Dependent variables in Column (1) and Column (2) is an indicator of whether a student chooses math-science tracks at the end of tenth grade. Advanced math is an indicator of whether a student takes advanced math courses. Column (3) and Column (4) re-run the regression of STEM on single-sex indicator conditional on students' college enrollment.

Table 2.6: The Impact of Single-Sex Schools on Students' Interest and Understanding of Math

	10th Grade		11th Grade		12th Grade	
	Interest	Understanding	Interest	Understanding	Interest	Understanding
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Boys						
Single-sex (vs coed)	0.0701	0.130**	-0.0494	-0.00125	0.0581	0.0774
	(0.0593)	(0.0595)	(0.0440)	(0.0275)	(0.0458)	(0.0549)
N	1992	1992	1876	1876	1842	1842
Panel B. Girls						
Single-sex (vs coed)	-0.00672	-0.0427	-0.0636**	-0.0552**	-0.0246	-0.0719
	(0.0473)	(0.0589)	(0.0306)	(0.0251)	(0.0856)	(0.0818)
N	1756	1756	1692	1692	1653	1653
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Student Controls	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Robust standard errors are clustered by school in parentheses; * p<0.10 ** p<0.05 *** p<0.01. All regressions include district fixed effects. Individual controls include an indicator for living arrangement (living with both parents, single parents, and grandparents or other relatives), number of the sibling, the birth order of child, and an indicator for at least one parents having a college degree or higher. Interest represents the indicator of `I am interested in Math'. Understanding represents the indicator of 'I fully understand math course material'.

Table 2.7: The Impact of Single-sex Schools on Effort Index

	10th grade		11th grade		12th grade	
	Satisfaction	Effort Index	Satisfaction	Effort Index	Satisfaction	Effort Index
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Boys						
Single-sex (vs coed)	-0.0295	0.0895	-0.00924	0.214*	-0.0146	0.145**
	(0.0437)	(0.0843)	(0.0279)	(0.108)	(0.0251)	(0.0702)
N	1989	1992	1863	1876	1839	1842
Panel B. Girls						
Single-sex (vs coed)	0.00598	0.195**	0.0247	0.0941**	-0.0332	0.178**
	(0.0552)	(0.0755)	(0.0339)	(0.0441)	(0.0318)	(0.0811)
N	1754	1756	1687	1692	1650	1653
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Student Controls	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Robust standard errors are clustered by school in parentheses; * $p<0.10$ ** $p<0.05$ *** $p<0.01$. All regressions include district fixed effects. Individual controls include an indicator for living arrangement (living with both parents, single parents, and grandparents or other relatives), number of the sibling, the birth order of child, and an indicator for at least one parents having a college degree or higher. Satisfaction represents the indicator of `I am happy to go to school'. Effort Index represents the sum of the students' responses on whether (1) they come prepared (2) they concentrate on lectures, (3) they study class material in advance, (4) they review after class and (5) they do homework thoroughly. I standardized this composite effort index to have a mean equal to zero and a standard deviation to be one.

Table 2.8: The Impact of Single-sex Schools on Effort Index by Subject

	10th grade			11th grade			12th grade		
	Effort Index on								
	Korean	Math	English	Korean	Math	English	Korean	Math	English
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A. Boys									
Single-sex	0.0419	0.0803	0.0781	0.134	0.182*	0.0682	0.138*	0.156*	0.234**
(vs. Coed)	(0.0847)	(0.0744)	(0.0766)	(0.0818)	(0.100)	(0.0833)	(0.0744)	(0.0916)	(0.0990)
N	1985	1982	1987	1875	1870	1875	1840	1837	2076
Panel B. Girls									
Single-sex	0.0752	0.292***	0.105	-0.00106	0.147**	0.120*	0.253***	0.133	0.195**
(vs. Coed)	(0.0597)	(0.0935)	(0.0684)	(0.0591)	(0.0683)	(0.0599)	(0.0904)	(0.104)	(0.0904)
N	1744	1748	1753	1690	1688	1690	1651	1648	1651
District FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Student Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Robust standard errors are clustered by school in parentheses; * p<0.10 ** p<0.05 *** p<0.01. All regressions include district fixed effects. Individual controls include an indicator for living arrangement (living with both parents, single parents, and grandparents or other relatives), number of the sibling, the birth order of child, and an indicator for at least one parents having a college degree or higher. Satisfaction represents the indicator of `I am happy to go to school'. Effort Index represents the sum of the students' responses on whether (1) they come prepared (2) they concentrate on lectures, (3) they study class material in advance, (4) they review after class and (5) they do homework thoroughly. I standardized this composite effort index to have a mean equal to zero and a standard deviation to be one.

Chapter 3: Is the Gender Gap in School Performance and STEM Major Choice Affected by the Sex of the Teacher?

1. INTRODUCTION

The gender gap in academic achievement, with girls generally outperforming boys in language and boys generally outperform girls in math, has long been of interest to educators and policymakers. Although there is increasing evidence that the gender gap in school performance is closing in math and science, women are still underrepresented in a STEM major and the STEM workforce. It is important to understand the factor determining this gap, because it may derive lasting consequences on gender differences in career choices, and labor market outcomes.

One explanation that has been discussed in the literature emphasizes the role of teacher gender. First, the gender of the teacher can have an impact on students' students' performance through role model effects. Students' performance will be enhanced when they are assigned to a same-sex teacher if they identify themselves with such a role model (Carrell et al., 2010). In other words, female students are exposed to successful women in STEM when assigned to female math or science teachers, and may, therefore, be inspired by them to go into these fields. These results are also consistent with the theory of stereotype threats, which states that students may react to teacher gender by internalizing an expected negative stereotype about their gender (Holmlund & Sund, 2008). Second, teacher gender may affect teachers' behavior. For example, female teachers may structure their classroom, select topics and provide examples differently than their male peers. If not preferences, gender stereotype about students may influence teachers' behavior, which may affect how they evaluate them (Lavy, 2008).

In this study, I examine the effect of the teacher-student gender matches on educational achievements, college enrollment, and STEM choices in high school settings. I avoid the problem of nonrandom selection and sorting of students to classrooms by exploiting a unique feature of secondary education in South Korea: the random assignment of students into a classroom each year. Utilizing student-level administrative data from Seoul, I track students' academic outcomes from 10th grade through 12th grade as well as outcomes related to future career choices including college enrollment and choice of STEM major.

I find that the presence of a female teacher substantially increases female students' test scores compared to male students, but there little same-gender teacher effect for male students' test scores. I further test whether the positive same-gender teacher effect for female students lasts until high school graduation. The results show that female students who are matched with a female teacher at 10th grade outperform scoring between 0.26 and 0.30 of a standard deviation higher than female students taught by a male teacher at 10th grade through 12th grade. Male students are insignificantly affected by switching a male teacher to a female teacher in terms of test scores.

In addition to this, I also show that students are influenced by teacher gender when they make decisions related to their career and future labor market outcomes. I look at three outcomes: whether the student chooses the math-science track at the beginning of 11th grade, whether the student decides to take advanced math courses that are required for STEM college major, and whether the student chooses STEM major when they attend college. The results show that female students are significantly less likely to choose the math-science track in high school, and they consistently less likely to choose a STEM major in college. Unlike the contemporaneous effects of teacher-student gender matches, I find that on average no significant evidence having a same-gender teacher affects a female students' STEM outcomes, which is comparable to the findings in Carrell et al. (2010).

I contribute to extensive studies examining the association between female teacher and academic outcomes of female students. Using the random assignment of students and faculty to courses, Carrel, page and West (2010) find that on average female students in the introductory science and math courses perform better when they taught by a female instructor. Most similar to this paper's setting, Lim and Meer (2017) and Lim and Meer (2018) show that female students taught by female teacher in 7th grade perform substantially better on standardized tests using classroom random assignment of students in middle schools. This paper extends the analysis of the effect of teacher gender role beyond academic achievement to examine other important decision such as track choice, STEM major choice, and college enrollment under the upper-secondary educational setting.

This paper is also closely related to an emerging body of literature that attempts to understand the presence of faculty role models in the STME major choice decision. The fraction of female and/ or minority faculty in STEM department is very low, so if role models of the same gender or race are important factors in major choice, this could play an important role in understanding the persistence of under-representation of women and minorities in STEM field. Hoffman and Oreopoulos (2009) finds that own-gender instructor in a math or science course decreases female students' performance and the number of same subject courses taken in later years. Carrell, Page, and West (2010) and Price (2010) shows that female students taught by female faculty experience no increase in likelihood of taking future math and science courses and no effect on graduating with a STEM degree. Bettinger and Long (2005) observed that female faculty members increase the probability of female students taking additional courses in math and geology. However, they identified the opposite effect for biology and physics courses. Different from these studies, I examine both contemporaneous and longer-run effect of teacher-student gender match at the beginning of the high school year.

The rest of the paper is organized as follows. Section 2 presents the classroom and teacher assignment process in South Korea. Section 3 describes the data used in this paper. Section 4 reviews the identification strategy. Section 5 presents the main empirical results. Section 6 concludes.

2. Institutional Setting

Middle school graduates in South Korea are randomly assigned to general high schools by the Office of Education in the Seoul metropolitan area. At the beginning of each academic year, high school students are assigned to classes, called "Bhans", of approximately 34 students, and each subject teacher visits the classroom to give a lecture. Following Korea's "Equalization Policy," the goal of the classroom assignment is to provide homogeneous “Bhans” in terms of student academic ability (Kang, 2007). The most common approach is to rank students by their academic achievement of the previous year and assign them across classrooms. For instance, if school has 3 classes in a given grade, the student with the highest score is assigned to the first classroom (“ 1 Bhan”), the student with the second highest score is assigned to the second classroom (“2 Bhan”) and the student with the third-highest test scores is assigned to the third classroom (“3 Bhan”), the student with the fourth-highest test scores are assigned to the third classroom (“3 Bhan”), and so on. This institutional feature provides evidence that students have no control over the choice of teacher gender and the peer group with whom they are required to spend the majority of their time within schools.

Even with this quasi-random classroom assignment of a student to the classroom, the internal validity of this study can be threatened if teachers are systematically assigned to those classrooms in a way that is related to their gender. For example, higher achieving students could be assigned to female teachers, which would produce upward-biased estimates of the effect of teacher gender. There are no strict rules for teacher assignment within a school in a given year, but anecdotal evidence suggests that teachers are assigned to classrooms in a manner unrelated to characteristics of either the teachers or the classroom’s students. I interviewed several current teachers and principals to gain insight into the process. In general, homeroom teacher assignment to class is determined either by lottery or by the decision of teacher committee at a school. These teachers, who teach a subject themselves, are responsible for discipline and manage student activities in school. Subject teachers are assigned to the classroom in an ad hoc way that is unrelated to student or teacher characteristics. For example, one subject teacher takes odd-numbered classroom while the others take even-numbered ones. These quasi-random classroom and teacher assignment prevent the selection problems and produce the random variation in teacher-student matching within a school.

3. DATA

3.1 The Dataset

My primary data set is the Seoul Education Longitudinal Study of 2010 (SELS 2010), which surveyed 10^{th}-grade students, parents, school, and teacher in 2010. Data are available through 12^{th} grade, with a follow-up survey after high school graduation on postsecondary outcomes. Subject teachers in Korean, Math, and English are linked to the students in 10th grade through 11th grade.

There are 235 academic high schools in Seoul, excluding one high school that is operated by the central government and five art and athletic high schools. Students in the 10^{th}-grade panel were sampled by stratified two-stage cluster sample design. First, 60 general high schools were randomly chosen from the population of 198 general high schools, 13 autonomous high schools were randomly selected from the entire 21 autonomous high schools, and all 10 special purpose high schools are surveyed. Second, two classrooms were then drawn randomly within the sample school. The base line sample consists of 5,240 of the 6,456 targeted students in 2010. In 2013, two months after high school graduation, students were surveyed about their postsecondary outcomes at that point; 83 % of high school graduates from the original survey respondents, are interviewed. 70% of the respondents are attended in university, 12.8% are preparing for college entrance, 11.5% are employed, and 4.3 % are unemployed and looking for a job.

Students' data include scholastic ability test scores for Korean, English, and Math administered by the Seoul Metropolitan Office of Education and Research Information Service, which took place after the first semester of the school year. The tests are low stakes, but these tests represent a useful proxy for students' educational attainment as the test's contents are well aligned with the high school curriculum. I standardize students' test scores to have mean zero and standard deviation equal to be one for ease of interpretation. Student characteristics include whether a student lives with married parents, whether both parents work, whether a father has a college degree or higher, whether a mother has a college degree or higher, whether a student attended private middle school, monthly household income, number of siblings and a student's birth order.

STEM outcomes are of particular interest since although the gender gap in math achievement in secondary education is small, women are substantially underrepresented in both STEM major and career. One of my major question in this study is whether having a same-gender teacher at the beginning of high school year affects students' decision on college enrollment and their choice of academic major. SELS re-interviewed respondents in the original sample to obtain information on students' development and educational transition. Using SELS-2010 and the follow-up survey, I also examine a student's decision to choose math-science trace within a high school that is highly associated with the student's actual STEM major (or department) in college, whether they enroll in college, and their choice of academic major.

Individual teacher-level data were obtained from the teacher survey in SELS-2010 and used to link students with their subject teacher within a year. Teacher characteristics include information on teachers' gender, an education level (B.A, M.A or Ph.D.), teacher's age, years of teaching experience, whether they graduated teachers' college, and whether they have administrative teacher responsibility.

3.2 Students' Assignment to Classrooms and Teachers

Throughout students' three years of high school study, students cannot choose their subject teacher, and subject teachers within the same grade provide a standardized national curriculum regulated by the government's education policy. These institutional characteristics assure there is no self-selection of students towards certain teacher. To test the validity of the research design, I compare the groups of students taught by the same- or opposite-gender teachers. If students are randomly assigned to the teachers of same- or opposite-gender teachers, the type of students assigned to a female teacher are nearly indistinguishable from those assigned to a male teacher.

Panel A of Table 3.1 presents mean differences in the characteristics of student-teacher parings when the teacher is female or male within schools by student gender. The results in Panel A show that there are no meaningful differences in students' characteristics whether they are matched with a female teacher. Panel B compares teacher's characteristics by student gender, but there are no significant differences in the types of teachers assigned to students of a different gender. These results further show that students and teachers are randomly assigned to classrooms irrespective of gender matches.

To examine whether there are no systematic differences in classroom assignment with respect to student and teacher gender, I regress teacher gender on students' observable characteristics, controlling for school by subject fixed effects. The results of this analysis are shown in Table 3.2, where I find that the correlation between teacher gender and students' predetermined characteristics is consistently small and statistically insignificant.

4. EMPIRICAL STRATEGY

To identify the contemporaneous effect of teacher-student gender matches, I estimate the following equation:

$$Y_{ijks} = \beta_0 + \beta_1 fs_i + \beta_2 ft_j + \beta_3 fs_i ft_j + X_{ij}\gamma + \phi_{js} + \epsilon_{ijks} \qquad (3.1)$$

Where Y_{ijks} is the standardized test score for student *i* taught by teacher *j* for subject *k* in 10th grade at school *s*. The test scores are normalized in each subject to have man zero and variance of one. The variable fs_i is equal to one if student *i* is female, and ft_t are indicator variables equal to one if subject teacher *j* is female, respectively. X_{ij} is a vector of student and teacher characteristics. Student characteristics include birth order, number of siblings, family income, indicators for parents are marred, both parents working, a father having a BA degree or higher, a mother having a BA degree or higher, and a student attended private middle school, birth order, number of siblings, family income.

Teacher characteristics include indicators for graduation from teacher's college, having a graduate degree, having less than five years of teaching experience, having administrative teacher responsibility, and being more than age 40. School by subject fixed effect, $\phi_{\mathrm{k}s}$, is included to compare students in a subject within a school.

I estimate the equation (3.1) by ordinary least square (OLS), which produces unbiased estimates given the random assignment of students and teachers to classroom. Standard errors are clustered at the school level to account for correlations among students within the same school. I use same specification to examine the contemporaneous effect of teacher-student gender match in 11^{th} grade.

$\beta 1$ is the average difference in academic achievement between female students and male students when paired with male teacher. $\beta 2$ indicates the impact of a female versus male teacher on performance for male students. The total effect of having a female teacher for female students can be obtained by adding $\beta 2$ to $\beta 3$, with $\beta 3$ as the differential effect on female students, as compared to male students, of having a female teacher. This last coefficient is the change in the gender gap between female and male students when switching from a male teacher to a female teacher.

To estimate the effects of teacher-student gender matches on longer term outcomes, such as taking an advanced math course, attending a college, or choosing STEM major, I estimate a variation of (3.1):

$$D_{ijkst} = \beta_0 + \beta_1 fs_i + \beta_2 ft_j + \beta_3 fs_i ft_j + X_{ij}\gamma + \phi_{js} + \epsilon_{ijkst} \qquad (3.2)$$

Where D_{ijt} is a dummy variable that indicates whether student *i* at time *t* chose to take an advanced math course or chose a STEM major. As before, the β coefficients are the coefficients of interest.

5. RESULTS

5.1 Contemporaneous Effects of Teacher Gender

Table 3.3 presents the results for the effects of teacher-student gender matches on students' standardized test scores in that year. Column (1) gives estimates with the most parsimonious specification that includes no additional controls. Column (2) includes school by subject fixed effects to compare students in a subject within a school. Column (3) and Column (4) adds student characteristics and teacher characteristics, respectively.

Panel A of Table 3 shows the effect of teacher-student gender matches in 10th grade on students' standardized test scores in that year. The coefficient on the female student dummy in Column (1) of Panel A indicates that female students perform better than male students by 0.21 of a standard deviation across Korean, English, and Math when taught by a male teacher. The coefficient on the female student x female teacher indicator in Column (1) shows that the change in the performance gap between female and male students when switching from a male teacher to a female teacher is 0.17 standard deviations. This effect consists of a statistically insignificant decrease in male students' performance of 0.12 standard deviations and an increase in female students' performance of 0.05 standard deviations. In other words, the gender gap effect is composed of an opposite-gender teacher effect for switching from a male teacher to a female teacher for male students ($-\beta_2$) and a same-gender teacher effect for female student who switch from a male teacher to a female teacher ($\beta_2 + \beta_3$).

Including school by subject fixed effect in Column (2) and student controls in Column (3) do not meaningfully affect the estimates of this gender gap effect in 10^{th} grade. In my fourth and preferred specification, I add controls for teacher characteristics in Column (4). The estimated impact of teacher-gender match on 10th grade academic performance of female students who are paired with a female teacher relative to a male teacher increased to 0.26 of a standard deviation, and it is statistically significant. However, adding controls across specifications do not meaningfully changes the pattern of the gender gap effect.

Panel B of Table 3.3 shows the effect of teacher-student gender matches in 11^{th} grade on students' standardized test scores in that year. The coefficient on the female student dummy in Column (1) of Panel B indicates that female students perform better than male students by 0.10 of a standard deviation across Korean, English, and Math when taught by a male teacher. The coefficient on the female student x female teacher indicator in column (1) shows that the change in the performance gap between female and male students when switching from a male teacher to a female teacher is 0.23 standard deviations.

Including school by subject fixed effect in Column (2), student controls in Column (3) and teacher controls in Column (4) do not meaningfully affect the estimates of this gender gap effect in 11th grade. Taken together, the results in Panel A and Panel B represents male students' performance is negatively associated with the opposite gender teacher match and teacher-gender matching has a positive effect on female students. Also, these results provide additional evidence that teacher-gender math is uncorrelated with the observed characteristics. For the remainder of the paper, I report results from models similar to my third specification that includes school by subject fixed effects and controls for students and teacher characteristics.

5.2 Longer-term Effects of Teacher Gender

Table 3.4 shows the effects of teacher-student gender match on students' academic achievements for later years. Panel A presents results of 10th-grade teacher-student gender match and Panel B shows the results of 11th-grade teacher-gender match, respectively. I find that the gender gap effects persist up to three years after the initial teacher-gender match. Female students who are paired with a female teacher at 10th grade outperform scoring between 0.26 and 0.30 of a standard deviation higher than female students taught by a male teacher at 10th grade through 12th grade. Male students are consistently negatively affected by switching a male teacher to a female teacher. In panel B of Table 3.4, I further examine the impact of same-gender teacher match using the teacher-student gender match at the beginning of 11th grade. Results in Panel B does not meaningfully different from the results in Panel A, providing additional evidence that the impact of teacher-gender match may be persistent.

Table 3.5 provides the results from estimating the effects of teacher-student gender match on postsecondary outcomes. Column (1) through Column (3) shows the results of the 10th-grade teacher-student gender matches on overall college enrollment, two-year college enrollment, and four-year university enrollment, respectively. I find that male student who is taught by a female teacher instead of a male teacher are 8 percent more likely to attend a college and the effects are mostly concentrated on enrollment in a 4-year university. The coefficients on female student indicator and female students x female teacher indicator are small and statistically insignificant, which suggest that the impact of teacher gender on college enrollment is zero for female students.

In Table 3.6, I turn to examine the impact of teacher-student gender matches on STEM outcomes. STEM outcomes are of particular interest because the prevalence of women in a STEM career is lower than that of men even though the gender gap in math and science achievements are small. To examine the same gender teacher effects on STEM choices, I look at three outcomes: whether the student chooses a math-science track at the beginning of 11th grade, whether the student decides to take advanced math courses that are required for STEM college major, and whether the student actually chooses STEM major when they attend college. Column (1) of Table 3.6 presents the effect of teacher-student gender matches in 10th grade on students' math-science track choice at the beginning of 11th grade. The coefficient on the female student indicator shows that female students are 19 percent less likely to choose the math-science track in 11th grade compared to male students. The results in Column (1) suggest that there is no statistically significant same-gender teacher effect for female students and no gender gap effect emerges when both female students and male students are paired with a female teacher.

Similarly, Column (2) shows that female students are 18 percent less likely to take an advanced math course in 11th grade. The underrepresent of female students in STEM persist to students' major choice in a college. The estimates in Column (3) presents that female students are 20 percent less likely to choose STEM major when they attend a college. Once again, I find no significant same-gender teacher effect for female students and no significant teacher gender effect for male students. The results in Table 3.6 are similar to Carrell et al. (2010)'s findings that on average there is no statistically significant evidence that having a higher proportion of a female faculty affects a female student's STEM outcomes.

I further investigate whether subject teacher gender matters in the decision of college enrollment and STEM major choice. Estimates in Table 3.7 and Table 3.8 shows that subject teacher-student gender match at the 10^{th} grade is not associated with the students' education choice in colleges.

6. Conclusion

It is an international phenomenon that female students outperform male students in school. Female students' advantage in reading test score is persistent in all OCED countries, where at the same time gender gap in math and science are substantially reduced and even reversed in some countries in recent years (OECD, PISA 2018). However, female students are still underrepresented in STEM major and STEM occupation. In this paper, I investigate whether I can explain the gender gap in academic achievement, college enrollment, and STEM choice with the student-teacher gender match at the beginning of high school years. The empirical evidence provided in this study suggests that female students taught by a female teacher at the beginning of high school year experience the increases in the test scores by the end of the high school year. Results on STEM outcomes show that female students are less likely to choose STEM major when they taught by the opposite-sex teacher, but same-sex teacher effect does not emerge.

Table 3.1: Comparison of Mean Characteristics

A. Student characteristics

	Female Students				Male Students			
	Female Teacher	Male Teacher	P-value	Obs.	Female Teacher	Male Teacher	P-value	Obs.
Married Parents	0.865	0.867	0.857	3,724	0.884	0.888	0.799	4,048
	(.009)	(.015)			(0.01)	(0.016)		
Both Parents' Work	0.524	0.503	0.241	3,717	0.470	0.494	0.379	4,020
	(.015)	(.018)			(.019)	(.017)		
Father w/ BA or Higher	0.620	0.631	0.759	3,778	0.653	0.686	0.275	4,194
	(.029)	(.048)			(.034)	(.032)		
Mother w/BA or Higher	0.464	0.482	0.640	3,778	0.481	0.517	0.312	4,194
	(.03)	(.053)			(.038)	(.035)		
Birth Order	1.571	1.559	0.601	3,713	1.651	1.606	0.065	4,040
	(.018)	(.022)			(.024)	(.015)		
Number of Siblings	1.893	1.929	0.173	3,721	1.868	1.867	0.976	4,041
	(.022)	(.030)			(.028)	(.064)		
Attended Private Middle School	.292	.356	0.179	3,687	0.210	0.244	0.297	4,017
	(.042)	(.056)			(.028)	(.036)		

B. Teacher Characteristics

	Female Teacher				Male Teacher			
	Female Students	Male Students	P-value	Obs.	Female Students	Male Students	P-value	Obs.
Graduate Degree	0.390	0.466	0.311	4,577	0.358	0.361	0.967	3,395
	(.052)	(.061)			(.071)	(.061)		
Teacher's College	0.616	0.575	0.561	4,577	0.601	0.481	0.170	3,395
	(0.048)	(0.060)			(.076)	(.050)		
Homeroom Teacher	0.466	0.516	0.333	4,577	0.649	0.610	0.622	3,395
	(0.041)	(0.039)			(.060)	(.048)		
Age >40	0.332	0.329	0.960	4,542	0.617	0.751	0.113	3,360
	(.045)	(0 .053)			(.063)	(.058)		
Teaching less than 5 years	0.412	0.451	0.639	3,973	0.119	0.196	0.306	3,100
	(.052)	(0.069)			(.044)	(.064)		

Note: Each p-value is for a test of equality of means. Standard errors in parentheses are clustered at the school level.

Table 3.2: Likelihood of Having a Female Teacher

	Coefficient	S.E
Female Student	0.030	(0.029)
Married Parents	0.007	(0.012)
Both Parents Work	-0.007	(0.007)
Father w/ B.A or Higher	0.006	(0.010)
Mother w/ B.A or Higher	0.006	(0.009)
Family Income	0.000	(0.000)
Graduated Private Middle School	0.013	(0.013)
Number of Siblings	-0.009	(0.007)
Birth Order	0.010	(0.007)
Observations	6531	
R-squared	0.597	

Note: The dependent variable is an indicator for having a female teacher in 10^{th} grade, regressed on student characteristics, controlling for school by subject fixed effects. Standard errors in parentheses are clustered at the school level.

Table 3.3: Contemporaneous Effects

	(1)	(2)	(3)	(4)
	10th	10th	10th	10th
Panel A.				
Female Student	0.214*	0.215*	0.195*	0.096
	(0.119)	(0.109)	(0.111)	(0.137)
Female Teacher in 10th Grade	-0.123	-0.076	-0.062	-0.075
	(0.088)	(0.092)	(0.089)	(0.117)
FS X FT in 10th Grade	0.173	0.181	0.135	0.260*
	(0.120)	(0.117)	(0.117)	(0.143)
N	7797	7797	6410	5653
R-squared	0.026	0.219	0.246	0.247
	(5)	(6)	(7)	(8)
	11th	11th	11th	11th
Panel B.				
Female Student	0.105	-0.101	-0.149	-0.155
	(0.126)	(0.108)	(0.109)	(0.112)
Female Teacher in 11th Grade	-0.236**	-0.192***	-0.210***	-0.196***
	(0.089)	(0.070)	(0.063)	(0.064)
FS X FT in 11th Grade	0.235**	0.347***	0.322***	0.332***
	(0.117)	(0.086)	(0.086)	(0.086)
N	6608	6608	5440	5042
R-squared	0.02	0.217	0.235	0.239
Sch X Sbj FE		YES	YES	YES
Student Controls			YES	YES
Teacher Controls				YES

Note: Each column shows results from a sperate regression with standardized test score in that year. Dependent variable in panel A is 10^{th} grade test scores in Korean, English and Math standardized to have a mean zero and standard deviation equal to one. Dependent variable in panel B is 11^{th} grade test scores in Korean, English, and Math standardized to have a mean zero and standard deviation equal to one. Student controls include family income, number of siblings, birth order, indicators for married parents, both parents working, a father having a college degree or higher, a mother having a college degree or higher, attended private middle school. Teacher controls include indicators for graduated teacher's college, having a graduate degree, having less than five years of teaching experience, having administrative teacher responsibility, and being more than age 40. Standard errors in parentheses are clustered at the school level. * p<0.10 ** p<0.05 *** p<0.01

Table 3.4: Long-run Effects

	(1)	(2)	(3)
	10th	11th	12th
Panel A.			
Female Student	0.096	-0.125	-0.015
	(0.137)	(0.129)	(0.132)
Female Teacher in 10th Grade	-0.075	-0.179	-0.128
	(0.117)	(0.115)	(0.094)
FS X FT in 10th Grade	0.260*	0.296**	0.236*
	(0.143)	(0.144)	(0.121)
N	5653	5488	5256
R-squared	0.247	0.224	0.254
		(4)	(5)
		11th	12th
Panel B.			
Female Student		-0.155	-0.045
		(0.112)	(0.102)
Female Teacher in 11th Grade		-0.196***	-0.128
		(0.064)	(0.084)
FS X FT in 11th Grade		0.332***	0.266**
		(0.086)	(0.115)
N		5042	4832
R-squared		0.239	0.286
Sch X Sbj FE	YES	YES	YES
Student Controls	YES	YES	YES
Teacher Controls	YES	YES	YES

Note: Each column shows results from a separate regression with school by subject fixed effect. Dependent variables in Column (1) through Column (3) in Panel A are test scores within a subject and a year standardized to have a mean zero and standard deviation equals to one, in 10^{th} grade through 12^{th} grade. Dependent variables in Column (4) through Column (5) in Panel B are test scores within a subject and a year standardized to have a mean zero and standard deviation equals to one, in 11^{th} grade through 12^{th} grade. Student controls include family income, number of siblings, birth order, indicators for married parents, both parents working, a father having a college degree or higher, a mother having a college degree or higher, attended private middle school. Teacher controls include indicators for graduated teacher's college, having a graduate degree, having less than five years of teaching experience, having administrative teacher responsibility, and being more than age 40. Standard errors in parentheses are clustered at the school level. * $p<0.10$ ** $p<0.05$ *** $p<0.01$

Table 3.5: Effects on College Enrollment

	(1) College	(2) 2yr College	(3) 4yr College
Female Student	0.058	0.009	0.049
	(0.062)	(0.032)	(0.055)
Female Teacher in 10th Grade	0.081***	-0.003	0.084***
	(0.029)	(0.026)	(0.029)
FS X FT in 10th Grade	0.003	0.032	-0.029
	(0.044)	(0.031)	(0.046)
N	5771	5771	5771
R-sq	0.105	0.104	0.092
Sch X Sbj FE	YES	YES	YES
Student Controls	YES	YES	YES
Teacher Controls	YES	YES	YES

Note: Each column shows results from a separate regression with school by subject fixed effect. Dependent variables are indicator for (1) whether a student goes to college, (2) whether a student attends 2-yr college, (3) whether a student attends 4-yr university. Standard errors in parentheses are clustered at the school level. * $p<0.10$ ** $p<0.05$ *** $p<0.01$

Table 3.6. Effects on STEM Outcomes

	(1) Track	(2) Advanced Math	(3) STEM
Female Student	-0.188***	-0.179***	-0.198*
	(0.042)	(0.041)	(0.099)
Female Teacher	-0.016	-0.030	0.037
	(0.040)	(0.041)	(0.060)
FS X FT	0.024	0.028	-0.084
	(0.046)	(0.046)	(0.070)
N	5497	5481	3014
R-sq	0.097	0.091	0.129
Sch X Sbj FE	YES	YES	YES
Student Controls	YES	YES	YES
Teacher Controls	YES	YES	YES

Note: Each column shows results from a separate regression with school by subject fixed effect. Dependent variables are indicator for (1) whether a student chooses math-science track in 11th grade, (2) whether a student takes advanced math courses, and (3) whether a student chooses STEM major in a college. Standard errors in parentheses are clustered at the school level. * p<0.10 ** p<0.05 *** p<0.01

Table 3.7. Effects on College Enrollment by Subject Teachers

	(1) College	(2) 2yr College	(3) 4yr College
Female Student	0.061	0.019	0.042
	(0.055)	(0.029)	(0.046)
Korean FT	0.024	-0.027	0.051*
	(0.025)	(0.019)	(0.026)
Math FT	0.054**	0.002	0.052*
	(0.024)	(0.025)	(0.028)
English FT	0.038*	-0.017	0.054**
	(0.022)	(0.018)	(0.022)
FS X Korean FT	0.011	0.042*	-0.030
	(0.033)	(0.023)	(0.035)
FS X Math FT	0.004	0.007	-0.003
	(0.039)	(0.030)	(0.041)
FS X EnglishFT	0.003	0.005	-0.002
	(0.037)	(0.027)	(0.036)
N	5771	5771	5771
R-sq	0.098	0.096	0.084
Sch X Sbj FE	YES	YES	YES
Student Controls	YES	YES	YES
Teacher Controls	YES	YES	YES

Note: Each column shows results from a separate regression with school by subject fixed effect. Dependent variables are indicator for (1) whether a student goes to college, (2) whether a student attends 2-yr college, (3) whether a student attends 4-yr university. Standard errors in parentheses are clustered at the school level. * $p<0.10$ ** $p<0.05$ *** $p<0.01$

3.8. Effects on STEM Outcomes by Subject Teachers

	(1) Track	(2) Advanced Math	(3) STEM
Female Student	-0.181***	-0.168***	-0.221**
	(0.037)	(0.036)	(0.088)
Korean FT	0.000	-0.001	0.051
	(0.029)	(0.030)	(0.049)
Math FT	-0.017	-0.020	0.030
	(0.040)	(0.041)	(0.044)
English FT	-0.015	-0.018	0.037
	(0.027)	(0.028)	(0.035)
FS X Korean FT	-0.022	-0.024	-0.086
	(0.036)	(0.038)	(0.060)
FS X Math FT	0.037	0.032	-0.063
	(0.047)	(0.047)	(0.058)
FS X English FT	0.035	0.028	-0.041
	(0.040)	(0.040)	(0.045)
N	5497	5481	3014
R-sq	0.090	0.082	0.115
Sch X Sbj FE	YES	YES	YES
Student Controls	YES	YES	YES
Teacher Controls	YES	YES	YES

Note: Each column shows results from a separate regression with school by subject fixed effect. Dependent variables are indicator for (1) whether a student chooses math-science track in 11^{th} grade, (2) whether a student takes advanced math courses, and (3) whether a student chooses STEM major in a college. Standard errors in parentheses are clustered at the school level. * $p<0.10$ ** $p<0.05$ *** $p<0.01$

Appendix A

Appendix to Chapter 1

Table A.1: The Impact of Single-sex Schools on STEM Major Choice

	STEM w/o Nursing	STEM w/o Nursing & Education	STEM w/o Nursing	STEM w/o Nursing & Education
	(1)	(2)	(3)	(4)
Panel A. Boys				
Single-sex	0.067***	0.069***	0.086**	0.091***
(vs coed)	(0.022)	(0.021)	(0.034)	(0.033)
N	1992	1992	939	939
Panel B. Girls				
Single-sex	0.022	0.021	0.013	0.011
(vs coed)	(0.026)	(0.026)	(0.036)	(0.037)
N	1756	1756	970	970
District FE	Yes	Yes	Yes	Yes
Student Controls	Yes	Yes	Yes	Yes

Notes: Robust standard errors are clustered by school in parentheses; * $p<0.10$ ** $p<0.05$ *** $p<0.01$. All regressions include district fixed effects. Individual controls include an indicator for living arrangement (living with both parents, single parents, and grandparents or other relatives), number of the sibling, the birth order of child, and an indicator for at least one parents having a college degree or higher. Dependent variable in Column (1) is a student's choice of STEM major excluding Nursing. A dependent variable in Column (2) is a student's choice of STEM major excluding Nursing and STEM-related education major. Column (3) to Column (4) repeated regression of Column (1) to Column (2) conditional on students who enrolled in college.

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